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Volume I

PRODUCTION/COST ANALYSIS OF RAMJET ENGINES

VOUGHT CORPORATION
DALLAS, TEXAS 75222

DECEMBER 1977

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Final Technical Report April 1976 – June 1977

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The subject program was conducted for the purpose of generating cost information on ramjet engines and developing a methodology that could be employed to accurately predict production costs of ramjet engines. The methodology addresses many different ramjet types, sizes and production quantities. The methodology determines the cost of individual modules of ramjet assemblies based on similarity of the modules to baseline components that are identified in a cost handbook. (There are typically around 20 basic components of a (continued) over

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20. ABSTRACT (continued)

given ramjet to be costed.) The total cost of the engine is a summation of all the appropriate cost elements.

A significant accomplishment of the program was the development of a large cost data base on many different configurations, materials of construction and variations in manufacturing processes. This data base should provide a good foundation on which to build other cost data as it becomes available.

The costing methodology developed under this program has been shown to be fast (a complete ramjet engine cost exercise can be done in 3-4 hours with only a desk calculator). The methodology is flexible, allowing the cost estimator to substitute actual cost data where it may be available, and to include special factors where he feels they are warranted. The methodology is judged to be accurate. Although actual production data is not available for comparison, the bulk of the cost estimates were generated by detailed Industrial Engineering estimates.

This report summarizes the approach taken in defining the ramjet assemblies and sub-assemblies, the method employed in costing the ramjet components, the baseline cost data for all of the identified components, a description of the methodology, and example problems to illustrate how the methodology is applied. The report also identifies areas where the methodology can be improved and expanded. As the methodology is used by government and industry representatives, further improvements can be expected.

The cost handbook is published separately from the final report. Copies of the cost handbook are available through the Chemical Propulsion Information Agency (CPIA), Johns Hopkins Applied Physics Laboratory, Laurel, Maryland 20810, (CPIA Publication No. 288). The cost handbook is self-contained, complete with instructions on how to apply the methodology. It is presented in loose leaf format to allow future additions and/or changes.

FOREWORD

This final report was prepared by the Vought Corporation, Dallas, Texas, under U.S. Air Force Contract F33615-76-C-2043, Production Cost Analysis of Ramjet Engines. The work was administered under the direction of the Air Force Aero Propulsion Laboratory with Mr. Jack R. Fultz as the Project Engineer for the Laboratory. The work reported herein was performed during the period April 1976 through June 1977 at Vought under the direction of Mr. H. E. Reynolds, Project Engineer, Technical Research and Development. The principal Vought personnel whose efforts have contributed to the success of this investigation were Messrs. F. D. Allen, M. L. Brandt, T. E. Branum, H. T. Emmons, B. W. Looker, D. L. Norwood, R. P. Peterson, J. E. Rasmusen, and C. W. Simpson.

The draft document was submitted to the Air Force for review and approval in July 1977.

This technical report has been reviewed and is approved.

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TABLE OF CONTENTS

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LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

LIST OF TABLES

GLOSSARY OF TERMS

ALVRJ	Air Launched Low Volume Ramjet
CER	Cost Estimating Relationship
FMS	Fuel Management System
G & A	General and Administrative
GORJE	Generic Ordnance Ramjet Engine
IRR	Integral Rocket/Ramjet
LDR, LFDR	Liquid Fuel Ducted Rocket
LFRJ	Liquid Fuel Ramjet
SDR, SFDR	Solid Fuel Ducted Rocket
SFRJ	Solid Fuel Ramjet
TCPF	Total Cost Plus Fee
TDC	Total Direct Cost
TEC	Total Estimated Cost
WBS	Work Breakdown Structure

SECTION I
BACKGROUND

The concept of ramjet propulsion dates from 1913. Forerunners of today's ramjet propulsion designs began to appear in 1928 in Germany and France. Research on ramjet propulsion in England and the United States was begun during World War II. In the United States, this research culminated in the production of two fully operational ramjet engines for use on two missiles, the Bomarc and the Talos.

Since the Bomarc and Talos engines are not truly representative of current-day ramjets and because there has been no ramjet production program since that time, historical cost data are not available to the weapon system planners for making projections of ramjet costs for new tactical missile applications. Further, the limited cost data that are available on today's development-type ramjets may not be directly applicable to production programs.

These technology type hardware costs have been further distorted by the limited quantity of systems built. Because of the small numbers that have been built, most of them have been essentially "hand built", expensive hardware. Consequently, these hardware costs are neither representative of what could be achieved in production or consistent with the cost level that will be required for tactical missile applications.

Prior to this study the only specifically applicable work that had been published on ramjet cost prediction was the Booz-Allen study performed for the Naval Weapons Center (reference 1) and more recently an NWC Technical Memorandum by Mr. Andrew Victor (reference 2). The first study was directed toward generating cost and reliability predictions for two specific configurations: an integral rocket/ramjet and the Generic Ordnance Ramjet Engine (GORJE). The second study dealt with the generation of Cost Estimating Relationships (CERs) for a number of general ramjet engine types based on cost data available to the Navy from a variety of sources including proprietary production engineering cost estimates.

In recent years, mission requirements have emerged which can only be satisfied by ramjets. To demonstrate the cost effectiveness of ramjet powered missiles, several things must occur. First, a credible methodology must be available that will predict, with good accuracy, the cost of ramjet engines over a range of sizes and for a variety of configurations. Second, cost must be directly relatable to engine performance. Third, there must be a concerted effort on the part of both government and industry to investigate ways of reducing the cost of ramjets and ramjet components by the application of low cost fabrication processes and materials. Finally, attention must be given to the identification of ramjet life cycle cost (LCC) factors so that methods for reducing the costs of ownership can be developed.

This program provides considerable expansion of the ramjet costing data base to include a broad range of ramjet engine configurations, a significant range of engine sizes (6" to 18" diameter), and production quantities up to 5000 units. Very little has been done in relating performance to cost or investigating Life Cycle Costs, but it is believed this program provides a major step in the right direction and can provide a good costing base from which these other studies can grow.

SECTION II
PROGRAM OBJECTIVES

The primary objective of this program was twofold: 1) to develop a methodology from which the costs of parts, sub-components, components and sub-assemblies of ramjet engines could be accurately forecast and 2) to develop a cost estimating handbook. The methodology had to be applicable to a broad range of ramjet types as specified in the following statement from the Air Force Aero Propulsion Laboratory RFP:

> "The costing methodology to be developed shall be sufficiently flexible to permit production costs to be generated for the entire gamut of ramjet engine types ranging from the simplest pitot inlet, constant fuel flow (pressurized tank) design to the much more complex integral rocket/ramjet design with widely variable fuel flow (turbopump) capability."

The methodology also had to be presented in a form suitable for use by both government and industry. Additional objectives of the method were that the handbook permit rapid (4 hours or less) and accurate (Class 1, ± 10 percent) cost estimates for any of the ramjets when used by a competent (familiar with the methodology) estimator starting with a listing of the key parameters taken from the ramjet engine drawings.

The requirement that the methodology allow the prediction of costs down to the parts level dictated that the methodology employ a modular costing technique. The cost of a particular ramjet assembly would then be determined by selecting the appropriate modules, determining their fabrication costs and adding the costs of assembly of the modules into a complete ramjet system.

The modular costing approach has several advantages. First, it provides a great deal of flexibility in being able to determine the costs of many different configurations. It provides high visibility of costs from the complete ramjet assembly down to the component and part level so that the primary cost drivers in a given system can be readily identified. Finally, the data base can be easily expanded or modified without disturbing the validity of the model or the methodology.

A secondary objective that might be considered a derivative of the first objective was the establishment of a cost data base for ramjet components. The paucity of data in ramjet component fabrication has made it difficult for ramjet enthusiasts to know where to start to obtain system costs. A comprehensive collection of cost data resulting from this program provides an excellent starting place on which to build. Variation in component designs from that shown in the study or disagreements with presented cost data are minor perturbations that can be dealt with satisfactorily. This data forms a common base from which any ramjet cost estimates can start.

A final objective of the program was to demonstrate or verify the validity of the costing methodology. This has presented a real challenge because there is no current production ramjet engine program on which a hard comparison can be made. An alternate approach to methodology validity confirmation was taken and is described in subsequent sections of the report.

SECTION III
APPROACH

The generation of the cost methodology for ramjet engines was carried out in the following manner. First, a study was made to determine the overall types of configurations and arrangements of ramjet engines that should be covered by the methodology. From this, a general description of each ramjet type was made and the system Work Breakdown Structure (WBS) was prepared. Next, an identification was made of the primary structural configuration and component designs that would be required for each block of the system WBS's. This task required a detailed design description of many components including not only pictorial representations, but in many cases a detail description of the steps in the fabrication process.

Detail estimates of the baseline set of components were generated. The baseline components were sized to fit a nominal 15-inch diameter ramjet to take advantage of much available cost data that had been generated by Vought in earlier ramjet engine Design-to-Cost studies. Cost variations as a function of size change were determined for a number of specific components so that cost size factors could be established. Learning curves were also established for each of the major cost elements so that a quantity adjustment factor could be generated.

The next major task of the program was to organize the cost data into a handbook form that would be easy to use by a qualified estimator. Here, the modular approach was taken to provide maximum visibility of cost data.

The final task of the program was to exercise the methodology to verify its validity/accuracy by making comparison with a "known" system cost.

A more detailed description of each of the above tasks is given in the following sections of the report.

1. RAMJET ENGINE DEFINITION

A requirement of the program was to develop a costing methodology applicable to a large number of the ramjet engine types from simple pitot type inlet podded engines to the more sophisticated integral rocket/ramjet engines. In selecting the types and configurations to be included, special emphasis was placed on those systems currently under study and development by both the Air Force and the Navy.

Eight classes of ramjet engines were defined. Three of the ramjets are liquid fuel ramjets (LFRJ). The first one is an integral rocket/ramjet which utilizes a single pressure chamber for both the sustainer and the booster operation. This arrangement is particularly attractive for volume limited applications. The second engine employs a tandem or staged booster which is separated from the ramjet after the system reaches sustainer take-over speeds. The third LFRJ is a podded design where the ramjet inlet, combustor and sustainer nozzle are mounted separately from the missile airframe. The booster may be separated after ramjet take-over or it may remain with the missile during sustained flight. The fourth engine type is

a solid fuel ramjet (SFRJ) that utilizes a solid propellant which is burned with ambient air. The SFRJ also employs an integral booster/combustor pressure chamber to achieve even higher volumetric efficiency. Another significant feature of the SFRJ is the elimination of the requirement for fuel pumping, storage, and control. The fifth and sixth engine types are solid fuel ducted rockets (SFDR) (integral rocket/ramjet configuration and tandem or staged booster configuration). The SFDR which utilizes a fuel-rich rocket exhaust mixed with additional air to achieve an afterburning effect, offers potential advantages of high performance for low volume engines. The seventh and eighth engine types are liquid fuel ducted rockets (LFDR). These engines are variations of the SFDR (with IRR and staged booster configurations also) but with liquid fuel rather than solid fuel sustainer operation. Although this system is not currently under development by either of the services, the LFDR probably offers the highest performance potential for a given engine volume. It does, however, require rather complex fuel management systems which makes it very expensive for many missions.

The eight configurations that have been defined will be sufficient to characterize any current or future ramjet engine of interest to the military. A schematic illustration of these ramjet engines is given in Figure 1.

2. WORK BREAKDOWN STRUCTURE

A Work Breakdown Structure (WBS) was employed to segregate costs of the ramjet engines into smaller packages so that better visibility of key costs drivers would be possible. The usual method of constructing a WBS is to start at the top level, in this case a ramjet engine assembly, and subdivide it into major sub-assemblies; then divide the sub-assemblies into components, and so on until the smallest part is identified.

In one sense, a detailed WBS for each of the ramjet engines was needed to establish a breakdown of the costs to a level that could be meaningful to a person conducting a cost evaluation. In another sense, the WBS had to be somewhat general because limitless configurations had to be dealt with, and the cost methodology had to retain flexibility in regard to specific configurations.

The original plan was to segregate costs down to the parts level for presentation in the Cost Handbook; however, when it appeared that literally thousands of individual data sheets would be required, a new approach was taken. It was clear that the initial approach violated one of the program objectives of establishing a methodology capable of being exercised by hand and in a matter of a few hours.

The magnitude of the task is illustrated in Figure 2, which is a schematic of a Work Breakdown Structure for the LFRJ-IRR. Several levels of the WBS and the typical number of items at each level are shown. The numbers at the right signify the approximate number of blocks that might appear at each level. The product of the numbers shows that a potential of 3,000 to over 11,000 parts would require separate cost data presentations. Other ramjet types have as many as five sub-assemblies. Consequently, the number of parts requiring costing would be 4,000 to 14,000.

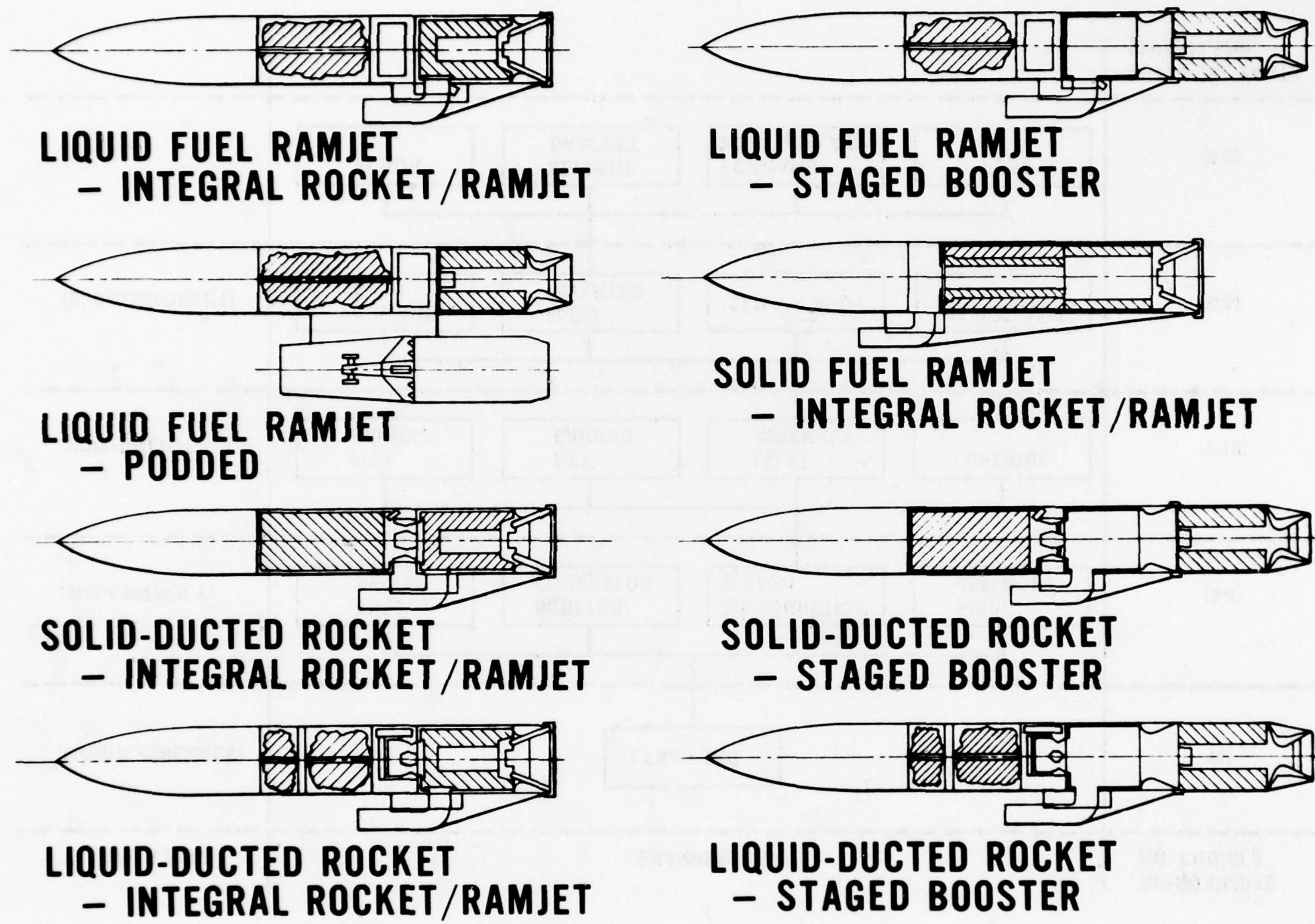


FIGURE 1 RAMJET ENGINE TYPES

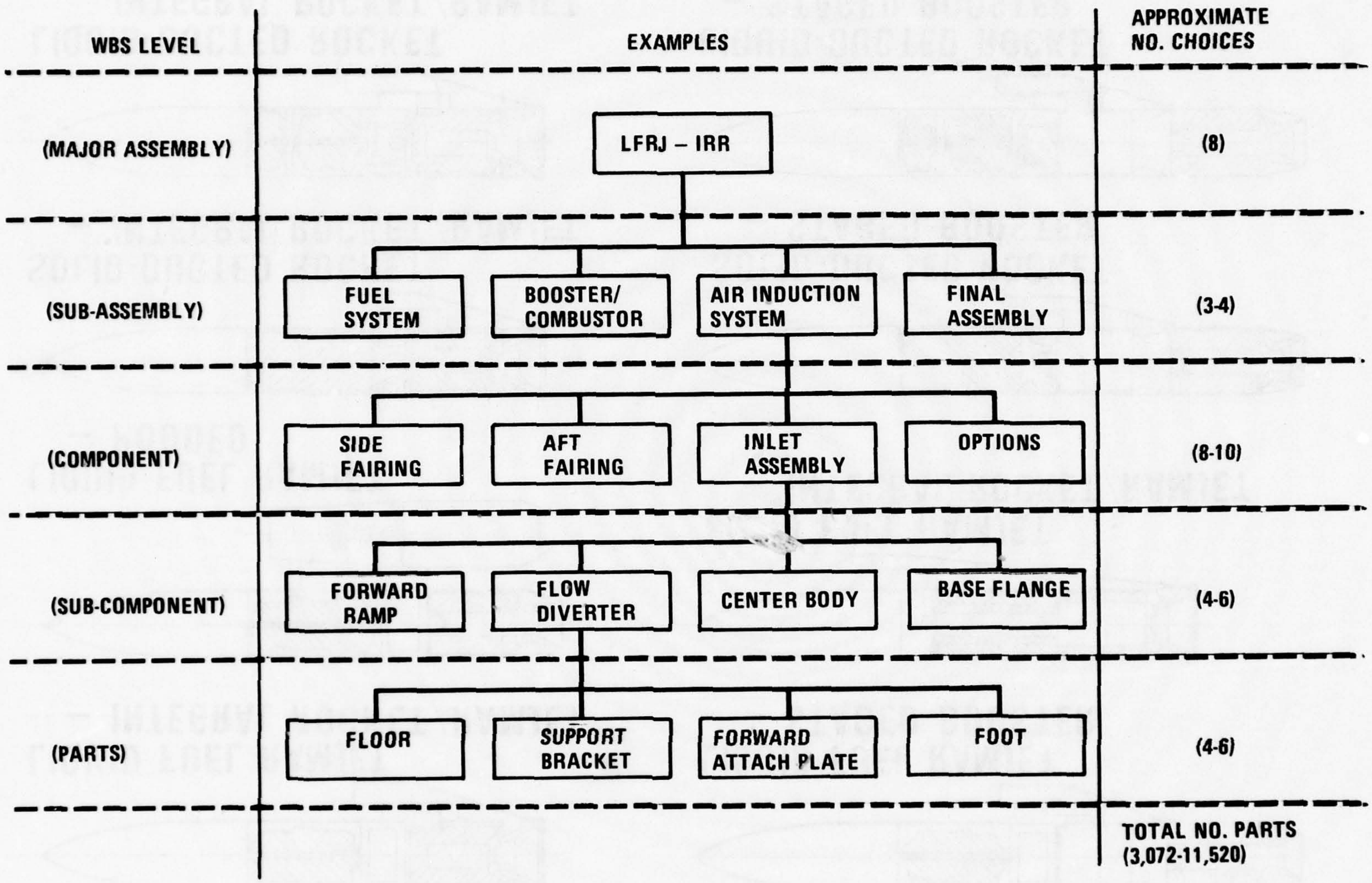


FIGURE 2 PARTIAL WBS OUTLINE SHOWING NUMBER OF CHOICES AVAILABLE

As a result, a closer evaluation of the level to which the WBS should be made was performed. A number of things was apparent. There is a large number of ways to design a particular element of a ramjet engine. For example, the forward attach plate shown in the WBS could be cut from sheet metal, stamped, forged, machined, or even cast. It could be attached by any number of methods from bolting on to laser welding; and although certain limitations on material choices would be expected, dozens of materials could be used to fabricate the plate. To investigate the cost of each approach would be a never-ending task.

A second observation revealed the specific part applied to only one unique design, and the part may or may not apply to a slightly different design. Another way of looking at it is in the previously discussed example, where the flow diverter could be redesigned to change the forward attach plate to a different arrangement, combined with another part, or perhaps even eliminated completely.

The net result of this evaluation was that the cost breakdown should extend only to the level where practical choices could be made by the cost evaluator. This level turns out to be the "component" level.

The definition of component is rather broad. It varies from an assembly of parts (like an inlet assembly) to a material (a particular kind of booster propellant) to a complete sub-system (fuel control system). A listing of the components is given in another section of the report.

After the decision was made to limit the WBS for each engine to the component level, a WBS was prepared for each of the ramjet types.

The system WBS for each of the eight ramjet engines is shown in the Cost Handbook which is published separately. An example of the type of WBS for one of the ramjets is shown in Figure 3. Note that the WBS is independent of a particular design. It is a general WBS for a ramjet type rather than a specific one of a given design. This is in keeping with the desire to make the cost methodology applicable to a large number of configu-tations. It is equally applicable to an engine with one inlet or four inlets or applicable to one with a chin inlet or an aft-mounted inlet. Therefore, these are the kinds of choices that the ramjet cost analyst must make to convert the general WBS to one for his specific design. This is accomplished by providing as many of the basic component variations as possible so that the cost evaluator can find a component that approximates the one for his particular engine. The cost of that component is then assumed to be repre-sentative for his component. As will be seen in a subsequent section, several hundred specific components have been identified exclusive of material choices that the cost evaluator may have for selection.

The decision to limit the detail cost breakdown to the component level satisfied the objective of having a fast, simple approach to gener-ating production costs for a particular engine. The WBS "Tree" in Figure 2 shows that a ramjet will be made up of 3 or 4 sub-assemblies, each having, typically, 8-10 components, thus giving each engine anywhere from 24 to 40

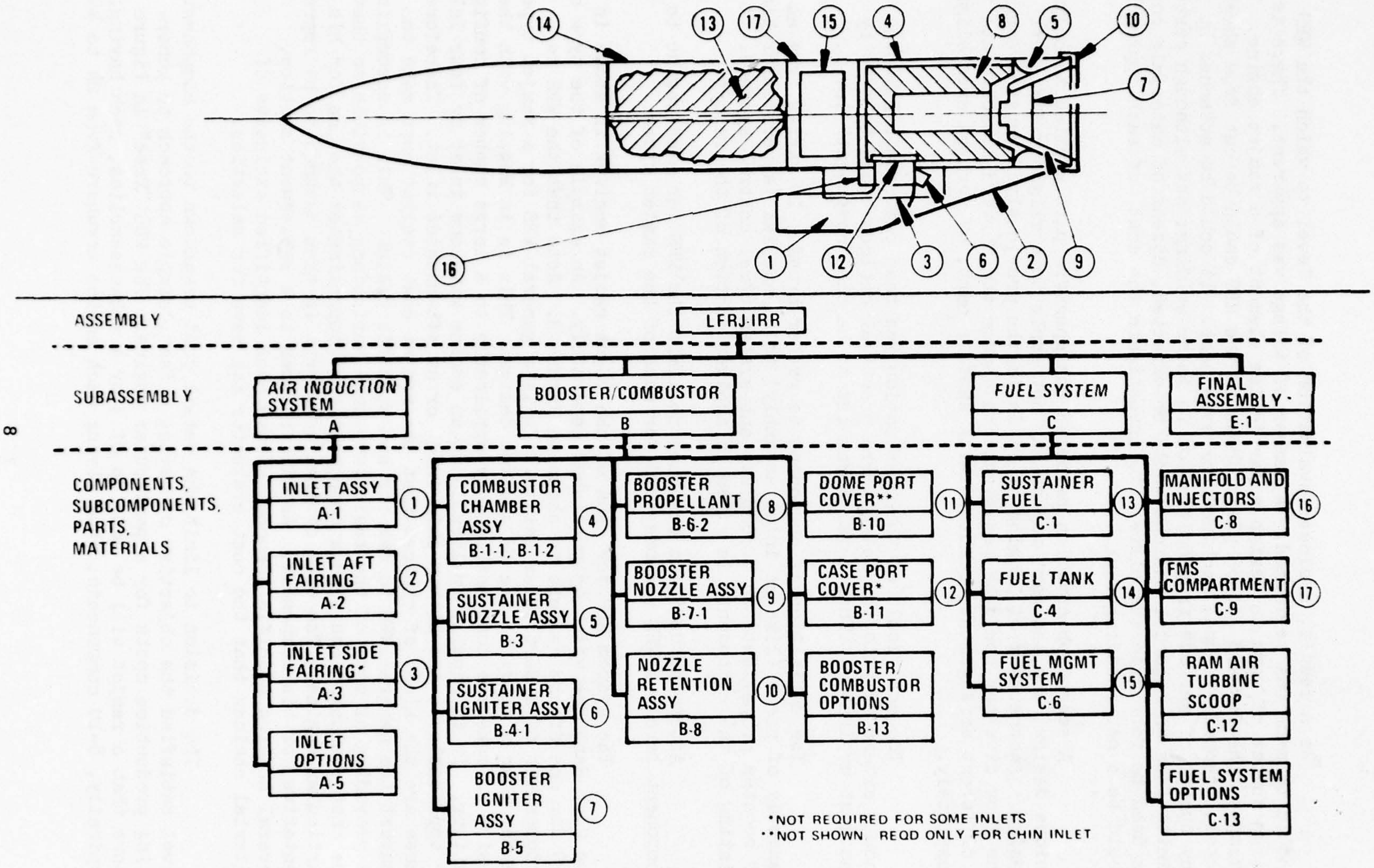


FIGURE 3 MAJOR ASSEMBLY WORK BREAKDOWN STRUCTURE - LIQUID FUEL RAMJET - IRR

individual components. The goal established at the outset of the program was that the methodology produced should allow the user to compute the cost of a ramjet engine in a period of 2 to 4 hours with no more than a slide rule or desk calculator. Allocating five minutes per calculation for each component, this methodology falls precisely in that time range goal.

3. APPROACH TO COST METHODOLOGY DEVELOPMENT

A number of techniques is employed to generate costs of production hardware. These range from the detail "Industrial Engineering" approach to the "top-of-the-head" estimates of the pseudo-expert. A brief study of the various costing methods was made to determine which was most applicable to the situation and the needs of this program. A review of some of the standard methods and their applicability to the program is discussed.

Industrial Engineering Approach - This technique, sometimes referred to as a "grass-roots" or "building-block" approach is based on establishing a Work Breakdown Structure or hierarchical tree of work elements which can be individually analyzed and estimated in detail. The estimates include every element of work associated with the production of that part and includes everything from buying the raw material to crating and shipping the final product. The total cost of the system is computed by summing the costs of each sub-element of the WBS along with whatever additional costs are required to assemble sub-elements into the final product.

For a given design, this approach is obviously the most accurate approach to cost estimation. For general usage, however, where specific designs are not available, the procedure does not have much significance and the estimates could be misleading. Within certain ground rules assumed for this program, the "Industrial Engineering" approach has been used extensively and essentially forms the backbone of the cost methodology developed. This will be discussed later.

Analogy Approach - This technique involves the direct comparison of the product in question to something already built and for which cost data exist. The costs are estimated on the basis of similarity to the product in existence. This approach has some good and bad features that should be noted. If the two products are very similar, then the production costs should be very accurately predicted. One must guard against automatically assuming the two production situations will be identical, however. For instance a labor strike, a materials shortage, a reorganization of a company, development of a new process or piece of equipment are examples of factors that can influence the final cost of a product and possibly distort the projected cost of a similar product. The analogy approach is, however, a valuable approach and has been employed extensively in the development of the cost methodology for this program.

Statistical Approach - This method requires large amounts of historical data. It is similar to the analogy approach in that it predicts cost on the basis of product similarity. The historical data base is statistically analyzed, by regression analysis methods or other mathematical

techniques, to produce cost as a function of some key parameter such as weight, size or performance level. These are generally referred to as CER's (Cost Estimating Relationships) and can be further used to investigate cost sensitivity. In one sense, the statistical approach is an improvement on the analogy approach because it tends to "Wash Out" or desensitize the cost to special factors such as those mentioned previously. One thing that tends to make it less accurate, however, is that it averages many designs into one composite design which may or may not be truly representative of the design in question. However, the technique is a valuable tool and was used a limited amount in this program.

"Expert-Opinion" Approach - This approach is a great simplification of the Industrial Engineering approach. It has been given many nicknames such as "SWAG", "Ball park" or "Top-of-the-head" estimating, but basically consists of an estimate by a person or persons having experience and knowledge of the costs of similar products. The cost estimate is generally arrived at with minimum or no formal cost breakdown. Buffalano, reference (15), describes a variation of this approach. It utilizes a group of "experts" making independent estimates which are statistically analyzed using a "Delphi" technique developed by the Rand Corporation. The results are then given to the evaluators to judge their own estimate in light of the analysis. The estimating procedure is repeated a second time and the results analyzed again. The technique has been used by NASA-Goddard and found to be relatively simple to use and effective. The general Expert-Opinion approach has been considered in this program to be a "last resort". In a few instances where neither specific cost data nor a specific design was available, the Expert-Opinion approach was the only way to obtain a cost estimate. In those instances the opinions were generally the result of a consultation with several knowledgeable people to accomplish, informally, the same kind of iterative process that the NASA estimators above employed.

The basic requirements of the Cost Methodology for this program were that it be fast (goal of four hours or less for a complete system estimate), accurate (goal of ± 10 percent), and simple (capable of being worked with slide rule or desk calculator). In order for the methodology to work for a variety of ramjet engine designs, it had to be flexible in order to permit cost evaluators to use their own cost data where desired.

The final approach to the development of the methodology utilizes all of the previously described approaches. The basic structure of the methodology and the bulk of the cost estimates were obtained using the detailed "Industrial Engineering" approach while a few of the components were obtained by "Statistical" and "Expert-Opinion" approaches. The basis for computing the cost of any given ramjet is predicated on its "analogy" or similarity to the components that are described and listed in the Cost Handbook.

The methodology centers on the selection and the manipulation of cost data for key components that have application to a variety of ramjet engines. A baseline set of components was defined and detail estimates of the cost elements of each component were made to arrive at a baseline cost for that component. Cost adjustment factors were produced that would allow the estimator to make corrections for size, quantity or production rate variation between the baseline and his situation.

To arrive at a cost for a given design, the estimator must break his system down into sub-assemblies and components in accordance with the suggested WBS for his particular type of ramjet. He selects components from the cost handbook that are similar in function and construction details. Cost data in the handbook is recorded on special computation forms provided and the cost data is "adjusted" in accordance with specific instructions to allow for variances from the baseline component. The adjusted cost of each component is recorded on a cost summary sheet where the estimator can compute the cost of the major sub-assemblies and the complete ramjet system. The system WBS provides a convenient checklist to prevent the user from overlooking certain cost elements of a particular ramjet. The methodology is set up to allow the user to simply fill in the blanks on certain data sheets to arrive at the complete system cost.

Flexibility is a key feature of the methodology. For example, if the cost estimator has some "hard" cost data on a particular component or sub-assembly, he is free to insert that cost data in the proper slot and ignore the corresponding cost estimate in the handbook. The total system cost is still a summation of the cost elements in the WBS and can include independent estimates as easily as those estimates in the handbook. This assumes that the estimator is substituting cost data that is truly interchangeable. The net result is an estimate in which the estimator can place even higher confidence.

The cost data in the handbook is considered to be very accurate for the baseline components; therefore, if the subject component is very similar in construction, the cost projection should also be accurate. If the subject component has some unique features or requirements that distinguish it from the baseline component, a cost difference would be expected. The methodology has been constructed to allow adjustments in the baseline cost data to compensate for design differences. In many cases it is not always straightforward as to what impact the design difference may have on component cost. It will be a matter of practical judgment.

4. BASELINE SYSTEM DESCRIPTION

The methodology described in the previous section requires the establishment of a complete set of ramjet components applicable to all of the ramjet types defined for the program. This has been done by reviewing all of the past and current ramjet programs to determine the configurations and characteristics that are prominent among the designs. For example, most of the work today is oriented toward air-launched ramjet missiles which, because of the weight and volume restraints, are predominantly integral/rocket/ramjet configurations. Information gathered from these programs shows the components that make up the integral rocket/ramjet have broad application to a large number of engines under development by both the Air Force and the Navy.

The Vought-developed ALVRJ (Air Launched, Low Volume Ramjet) ramjet engine has proved to be an invaluable source of information for this program.

The ALVRJ program, which dates back to 1968, has been the source of considerable ramjet technology development with many Design-to-Cost studies being conducted along the way. The ALVRJ system employs a liquid fuel integral rocket/ramjet propulsion system that is nominally 15 inches in diameter. The air induction system employs four concentric, 2-dimensional aft-mounted inlets. These supply air to the combustor chamber following burn-out of the booster and subsequent ejection of the boost nozzle and chamber port covers.

A more complete description of the ALVRJ ramjet and related systems can be found in reference (3). Figure 4 shows an inboard profile of the ALVRJ system. Although the ALVRJ system has not reached production status, there is an accumulation of cost data on the six prototype systems that were fabricated (five of which have been successfully flight tested) and many alternate component designs made in Vought's extensive Design-to-Cost program.

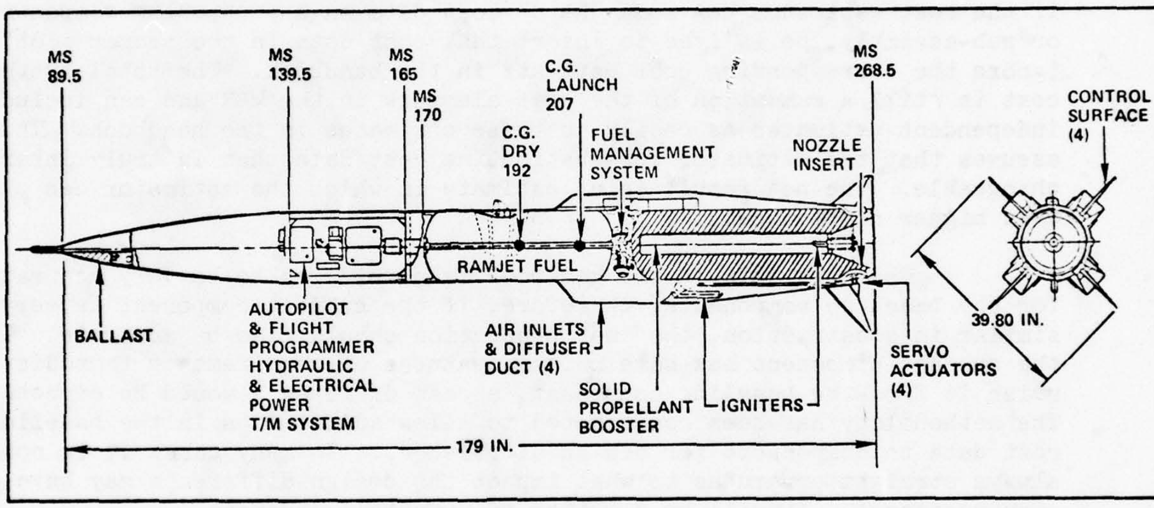


FIGURE 4 ALVRJ INBOARD PROFILE

The Baseline System for the Cost Methodology is built around many of the components present in the ALVRJ system in order to take maximum advantage of a data base which is believed to be accurate, very broad (covers a number of manufacturing methods and materials), and applicable to a large number of other ramjet configurations. Because the ALVRJ system utilizes a 15-inch diameter engine, (which is within the 6-inch to 18-inch diameter range selected for the study) and much of the cost data in the handbook are derived from that system, the baseline components are sized to a nominal 15-inch diameter engine.

Components required for other ramjet configurations not present in the ALVRJ or not part of one of the ALVRJ-related Design-to-Cost studies were also defined. Conceptual definitions were generated and sketches were made in order that detail estimates could be made. In order to be consistent with the Baseline System ground-rules, they were also sized to a nominal 15-inch diameter engine. A matrix of components and ramjet engines was constructed to make sure that all primary components of interest had been included in the Baseline System.

Minor design variations of the prominent configurations are also considered. For instance, the ALVRJ system employs 4 aft-mounted 2-D inlets; but the methodology is constructed in such a manner that if the cost estimator has only one or two aft-mounted 2-D inlets, proper adjustments can be made without invalidating the handbook cost data.

Additional configurations are also included in the Baseline System listing. In all, there are eight basic choices of inlet designs exclusive of material choice. Costs are projected for each of these designs -- thereby giving the user of the methodology a large number of inlets from which to select. Component choices were limited to current state-of-the-art designs. No attempt has been made to select a "best" or lowest cost design in the selection of components -- although many concepts do reflect low cost fabrication techniques. The components are all scalable up or down and are applicable to the full range of sizes specified for the program. Again, it might be observed that some of the component designs or fabrication processess may not be the best design for a particular size. It is conceivable that a smaller engine might be designed in such a way that standard tubing or other materials configurations could be employed in place of rolled, welded and machined materials and thereby save on production costs. In this regard, the baseline components listing might have included a description of components uniquely suitable to the smaller engine sizes; however, the constraint of time and money did not allow this to be explored fully. This is an area which could be done during a subsequent program.

One of the drawbacks to having a set of designs for the baseline is the possibility that the ramjet in question may have a component to be priced and there is not an equivalent design in the baseline data bank. This situation can be handled in one of two ways. The first option is to obtain a detail engineering estimate of the fabrication cost by qualified estimators familiar with manufacturing processes, tooling and materials costs. The second option is to find one or more components in the data bank that have similar characteristics and employ similar manufacturing processes and attempt to assign some degree of design complexity to the components of interest relative to the component in the data bank. This is the "Engineering Judgment" approach. Although it is a rough approximation, a simple parts-count comparison of the two components might be a first step in approximation of the relative cost of the two components. Provisions are made in the methodology for adjusting the cost whatever the reason might be for the needed adjustment.

Illustrations of many of the key components are shown in the following figures. Figure 5 shows eight basic inlet types -- four of which are typically aft-mounted and the other four are nose or chin inlets. Figure 6 illustrates some of the other air induction system components included in the data base, including some of the fairings and covers that go with the baseline inlets. Figure 7 shows only a few of the combustor chamber assemblies for the liquid fuel ramjet, solid fuel ramjet and ducted rocket. Note the three main types of construction: roll and weld, machined forging with shear spun case, and deep draw. Figure 8 illustrates the booster and sustainer nozzle concepts that are included. Figure 9 shows some of the booster and combustor miscellaneous hardware and options. Figure 10 shows the fuel tank configurations and some of the other fuel systems hardware. Figure 11 gives schematic drawings of four of the fuel control systems included in the data bank. The schematics illustrate the simplest to the most complex design for fuel controls. Figure 12 shows some of the miscellaneous hardware associated with the liquid fuel systems.

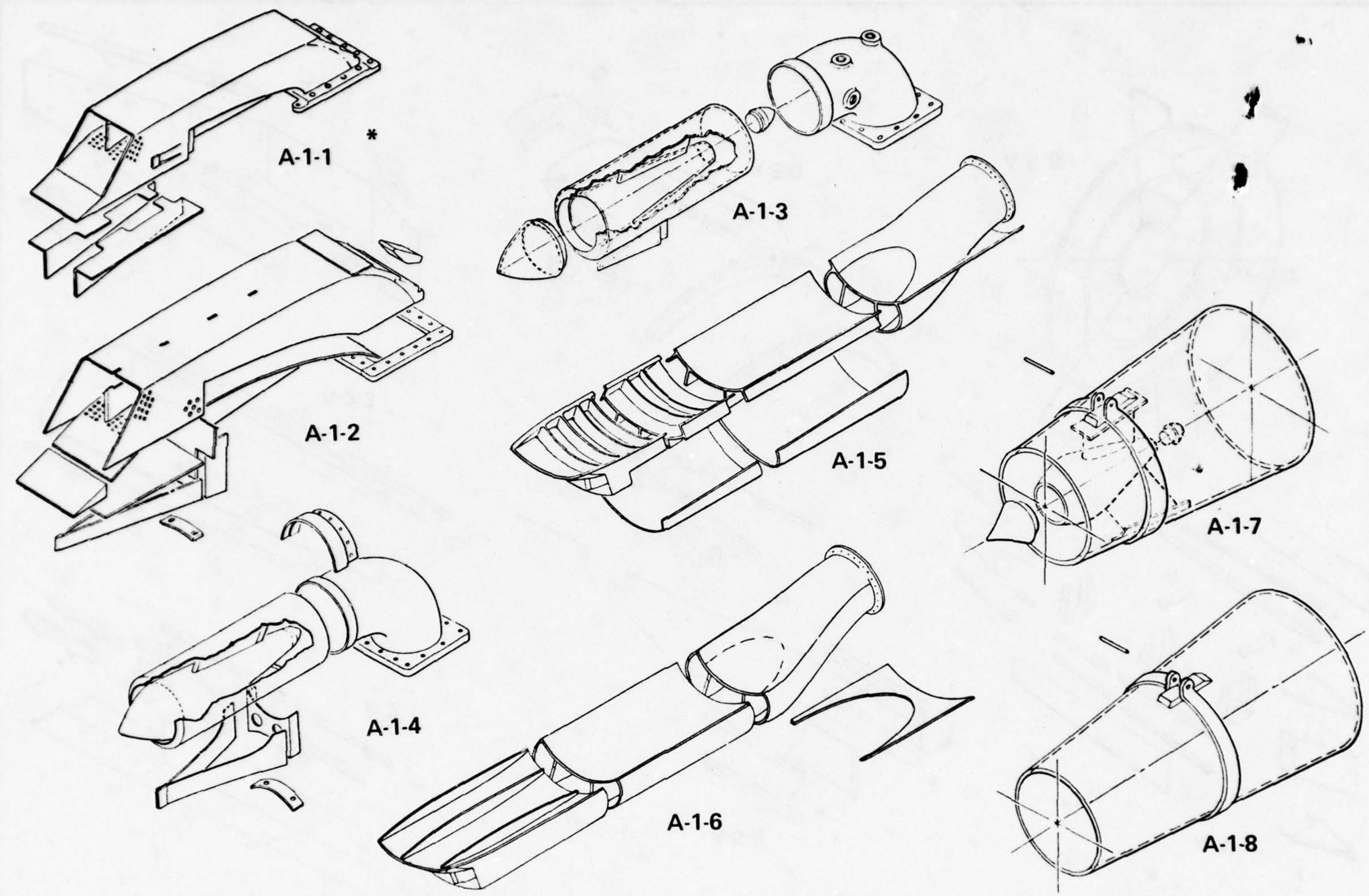
In all, there are over 125 specific components listed in the baseline components list. When the various options of construction materials, propellant formulations, and levels of design complexity are included, well over 300 basic choices are available to the cost estimator to find a match for his ramjet system. The key to using the methodology rests with the number and variety of component options that form the data base. If the baseline components adequately cover the field of choices, then the methodology will have accomplished the goals of the program. If there are vacancies in the data, they can be filled by simply adding the component configurations that are missing.

Table 1 gives a listing of all of the components in the Baseline Data. The alpha-numeric identification listed provides a key which is helpful in the assembly and application of the methodology. More complete descriptions and sketches of the components are presented in the cost handbook.

5. COMPONENT COST GENERATION

Projecting the cost of manufacturing any product is a hazardous business. Special situations and circumstances will cause one to challenge any set of cost figures that are reported. It is not expected that the methodology or the cost handbook generated under this program will prove to be an exception to that rule. For that reason, the assumptions used in generating costs for this program are carefully delineated in order that the reader may understand what the numbers represent and how they were obtained. Then, if he wants to make different assumptions, he is better equipped to use and/or modify the cost figures for his specific purposes.

Production costs here and in the cost handbook represent the selling price to the government by a prime contractor. The price includes all materials, sub-systems and services that are purchased or sub-contracted plus the prime contractor's costs and fee. Costs are production costs and do not include design or development costs. A detailed description of the labor rates, departmental overheads, burdens, and other factors will be described in later sections of the report.



* The alpha-numeric designation relates to a specific component design in the cost handbook.

FIGURE 5 INLET SYSTEM CANDIDATES

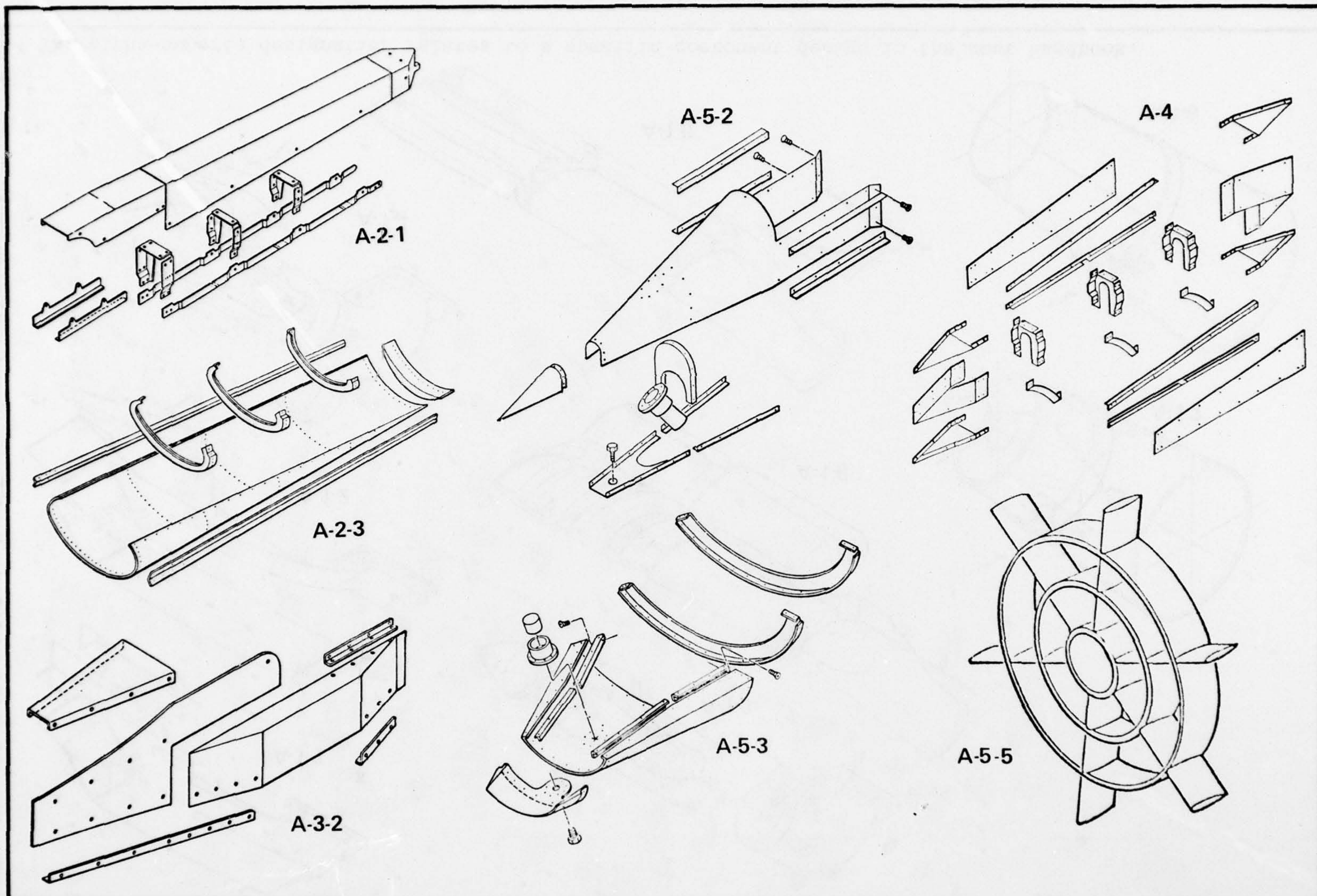


FIGURE 6 INLET FAIRINGS AND OPTIONS

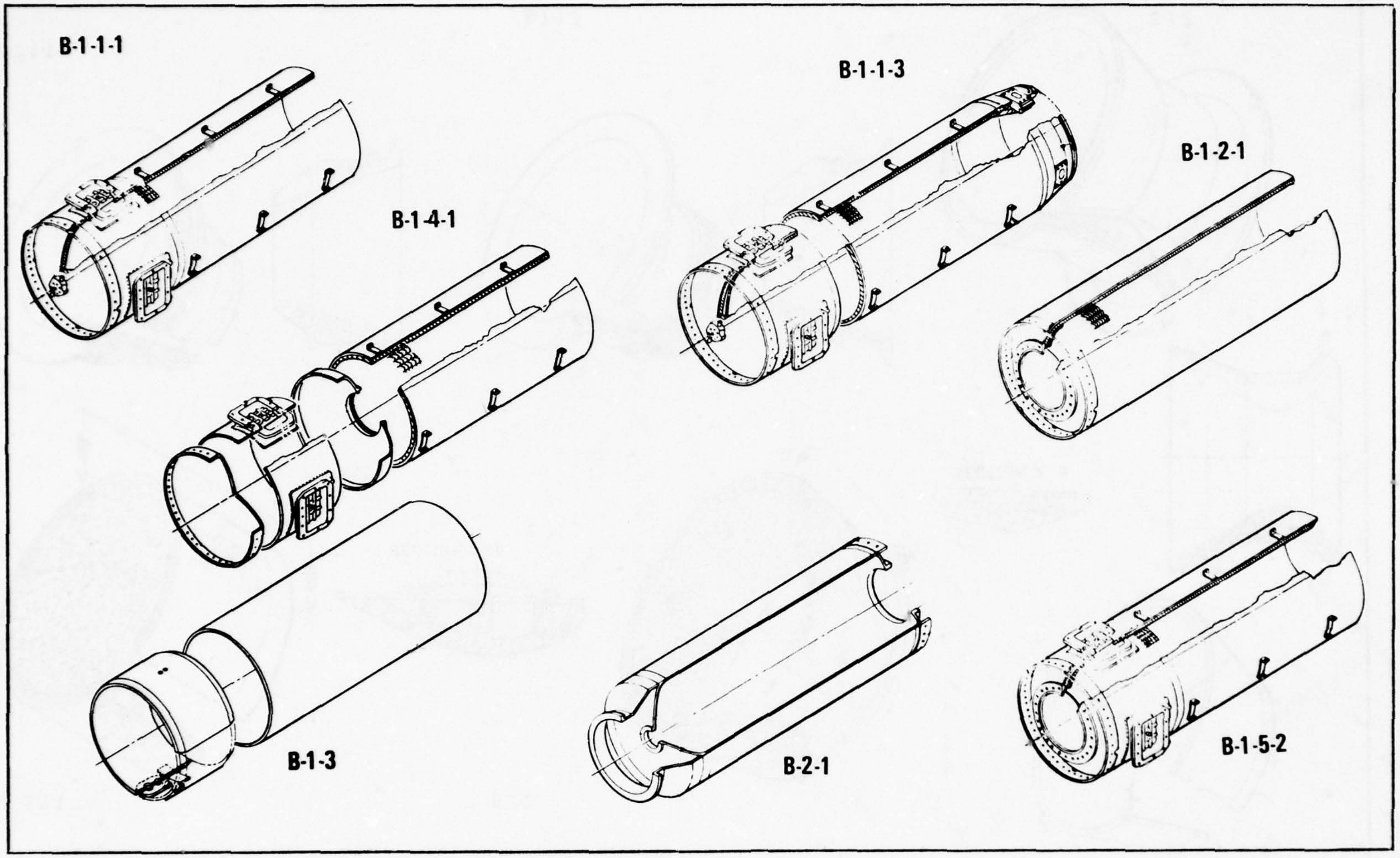


FIGURE 7 COMBUSTORS

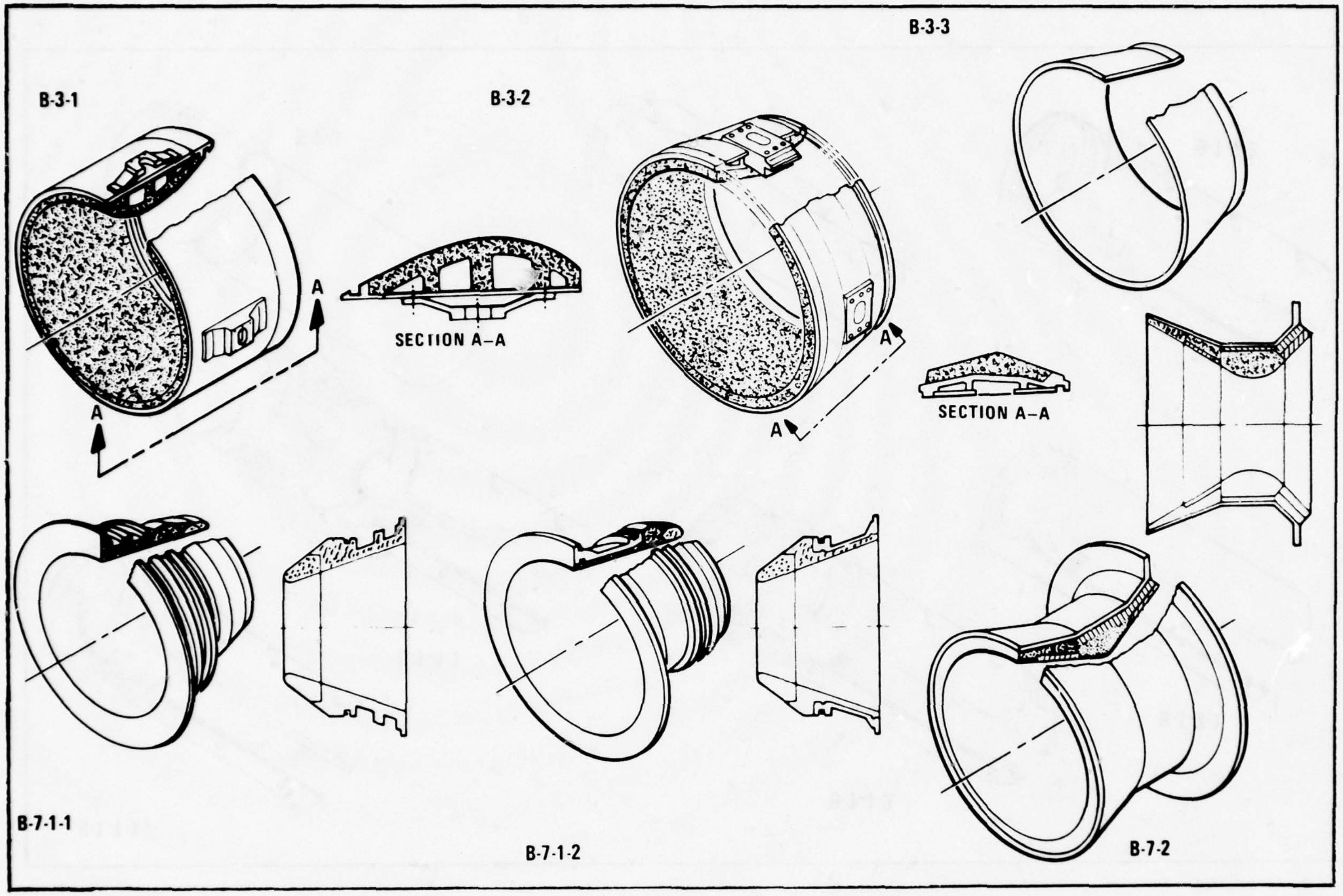


FIGURE 8 NOZZLES

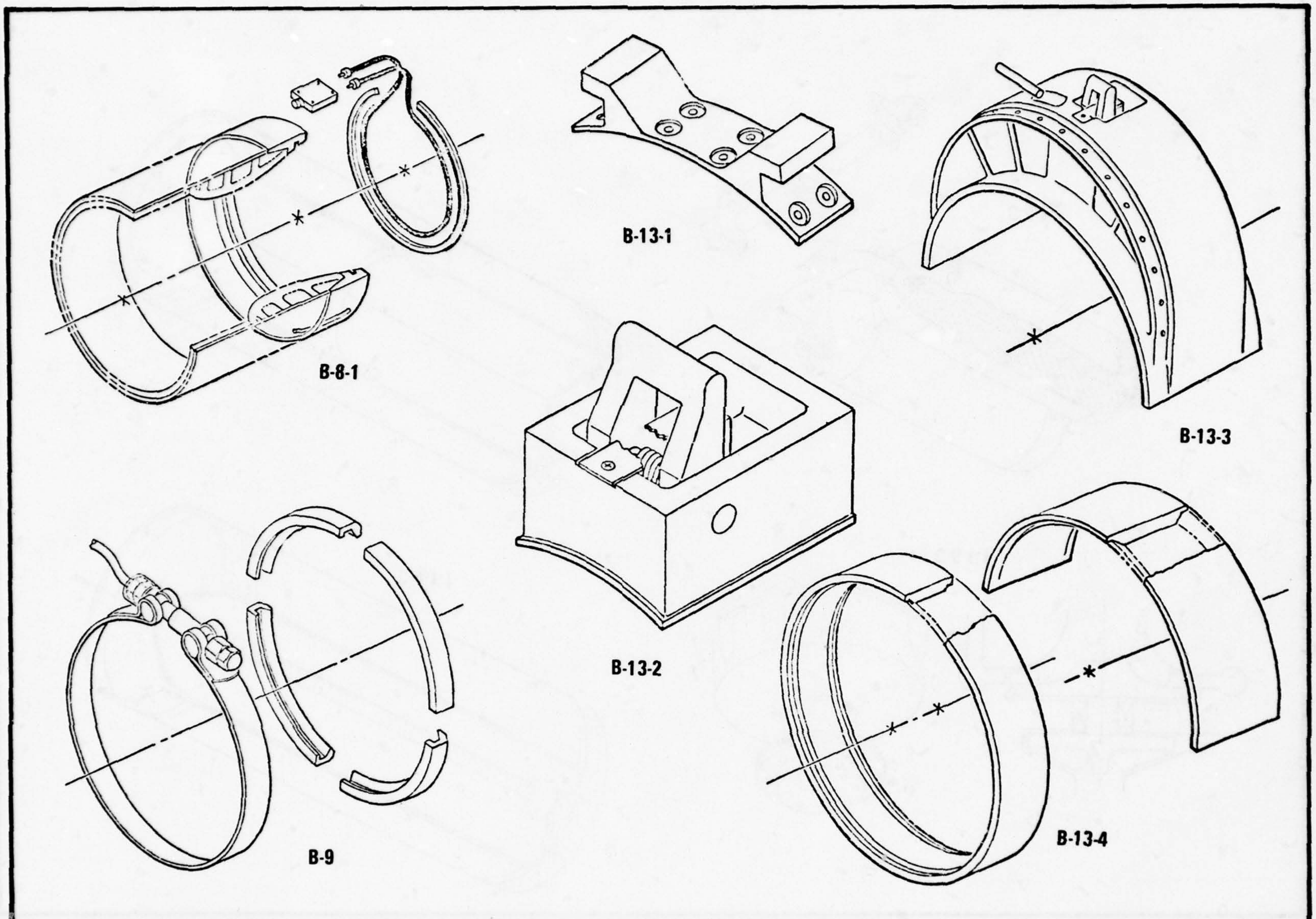


FIGURE 9 BOOSTER/COMBUSTOR MISCELLANEOUS HARDWARE

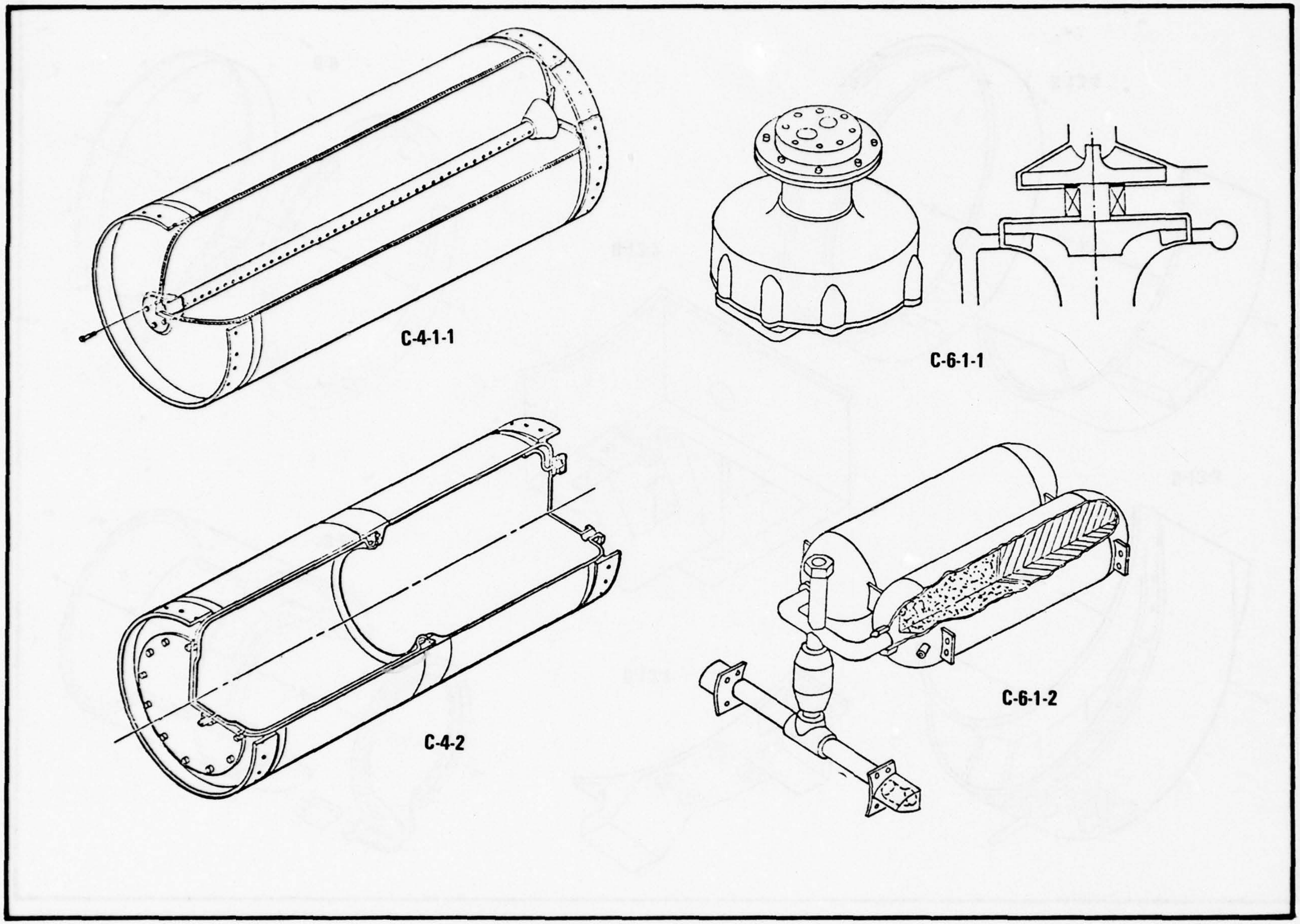


FIGURE 10 FUEL TANK HARDWARE

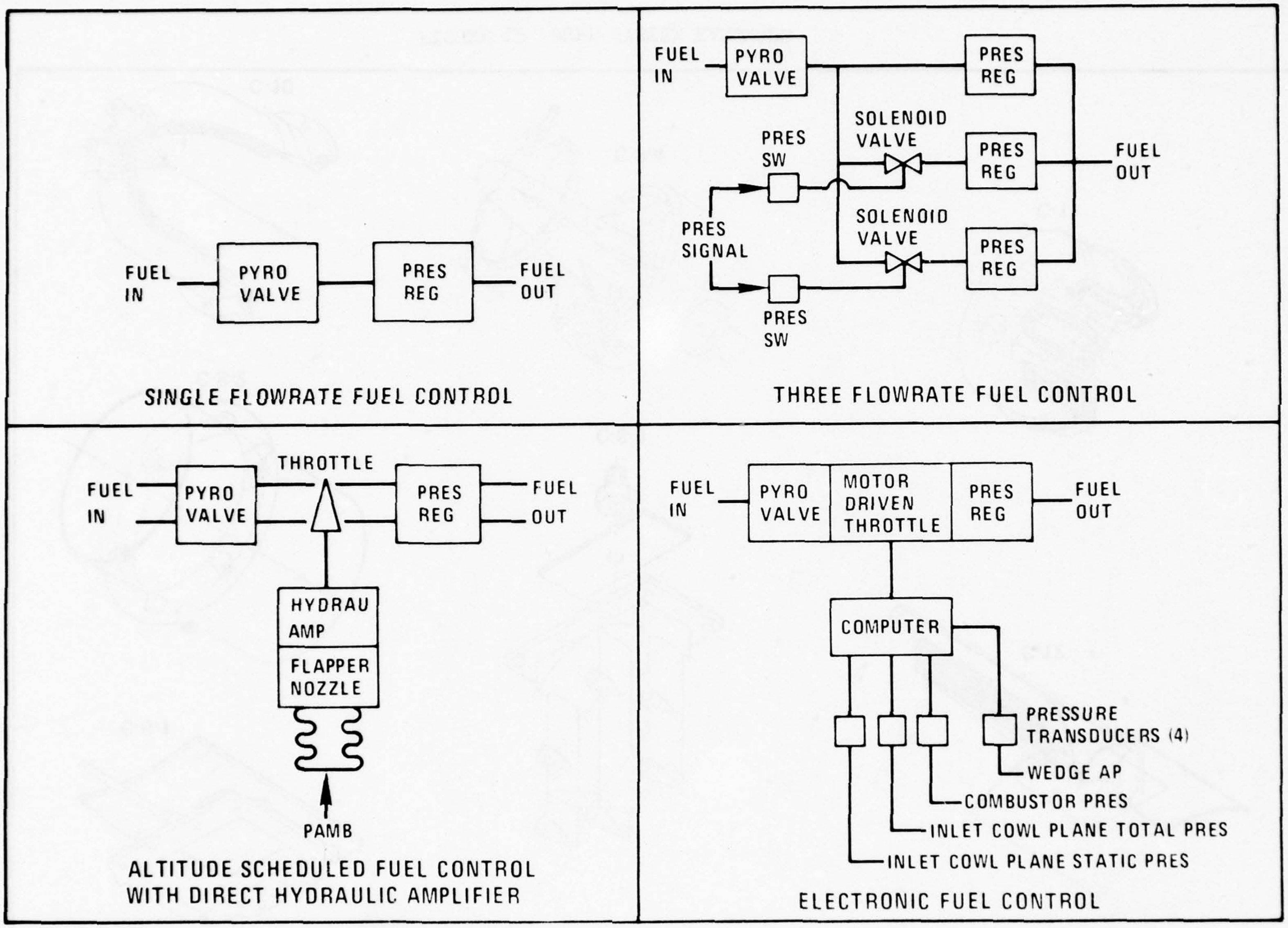


FIGURE 11 REPRESENTATIVE FUEL CONTROL SYSTEMS

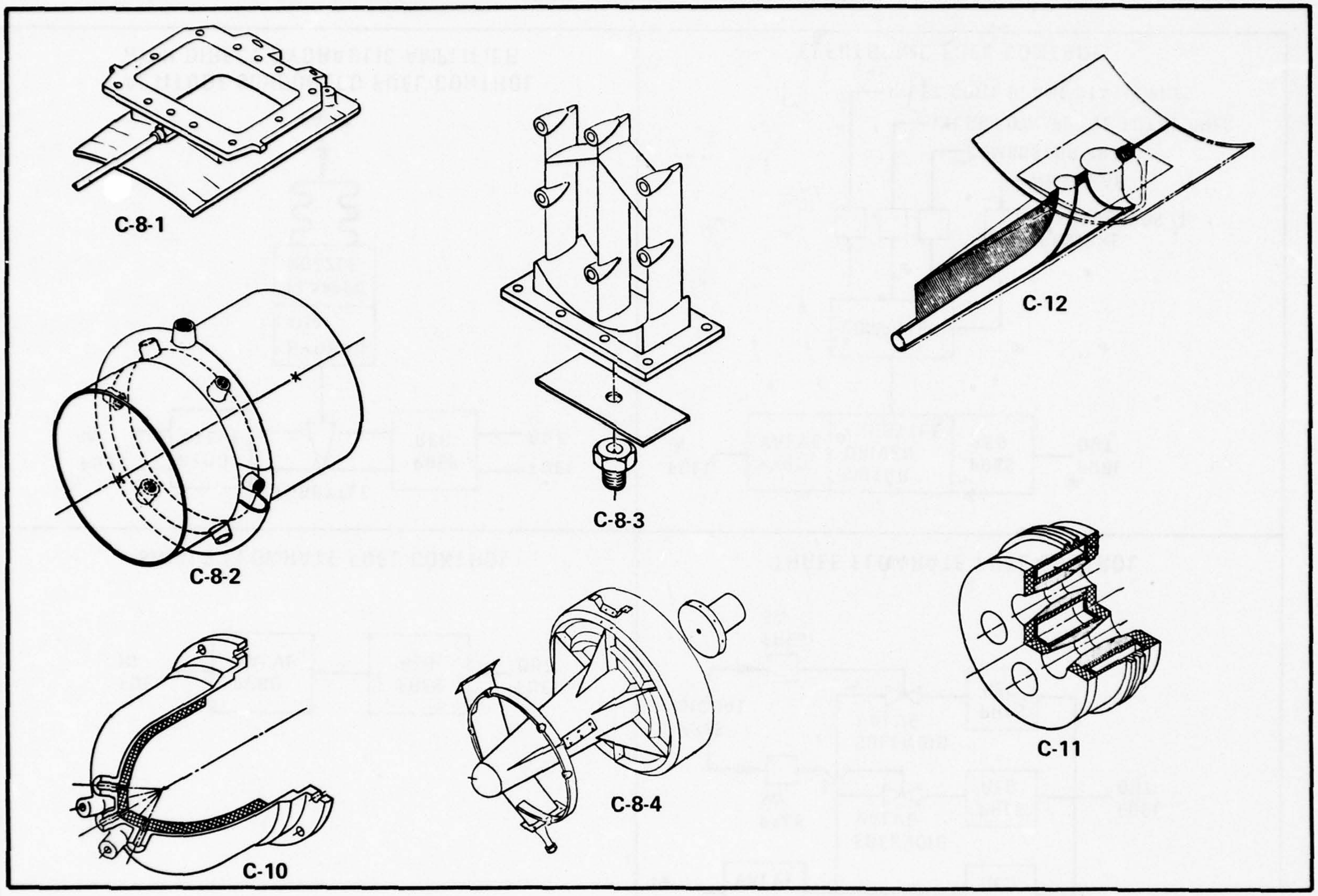


FIGURE 12 FUEL SYSTEM HARDWARE

TABLE 1

RAMJET COMPONENT MATRIX

AIR INDUCTION SYSTEM COMPONENTS

- A-1 INLET ASSEMBLIES
  - A-1-1 2-D AFT INLET ASSEMBLY - CAST CONSTRUCTION
  - A-1-2 2-D AFT INLET ASSEMBLY - SHEET METAL CONSTRUCTION
  - A-1-3 AXISYMMETRIC AFT INLET ASSEMBLY - CAST CONSTRUCTION
  - A-1-4 AXISYMMETRIC AFT INLET ASSEMBLY - SHEET METAL CONSTRUCTION
  - A-1-5 CHIN INLET ASSEMBLY - CAST/SHEET METAL CONSTRUCTION
  - A-1-6 CHIN INLET ASSEMBLY - SHEET METAL CONSTRUCTION
  - A-1-7 AXISYMMETRIC PODDED INLET ASSEMBLY - CAST/SHEET METAL CONSTRUCTION
  - A-1-8 PITOT PODDED INLET ASSEMBLY - SHEET METAL CONSTRUCTION
- A-2 INLET AFT FAIRINGS
  - A-2-1 2-D AFT INLET AFT FAIRING
  - A-2-2 AXISYMMETRIC AFT INLET AFT FAIRING
  - A-2-3 CHIN INLET AFT FAIRING
- A-3 INLET SIDE FAIRINGS
  - A-3-1 2-D AFT INLET SIDE FAIRING
  - A-3-2 AXISYMMETRIC AFT INLET SIDE FAIRING
- A-4 POD ATTACH FAIRING
- A-5 INLET OPTIONS
  - A-5-1 2-D INLET COVER
  - A-5-2 AXISYMMETRIC INLET COVER
  - A-5-3 CHIN INLET COVER
  - A-5-4 AIRFOIL TYPE AERODYNAMIC GRID-2D
  - A-5-5 AIRFOIL TYPE AERODYNAMIC GRID-CIRCULAR

BOOSTER/COMBUSTOR SYSTEM COMPONENTS

- B-1 COMBUSTOR CHAMBER ASSEMBLY (INTEGRAL OR NON-INTEGRAL DESIGN)
  - B-1-1 CHAMBER FOR AFT INLET DESIGN (LFRJ)
    - B-1-1-1 ROLL AND WELD CONSTRUCTION
    - B-1-1-2 DEEP DRAW CONSTRUCTION
    - B-1-1-3 MACHINED & SHEAR SPUN CONSTRUCTION
  - B-1-2 CHAMBER FOR CHIN INLET DESIGN (LFRJ)
    - B-1-2-1 ROLL AND WELD CONSTRUCTION
    - B-1-2-2 DEEP DRAW CONSTRUCTION
    - B-1-2-3 MACHINED & SHEAR SPUN CONSTRUCTION
  - B-1-3 CHAMBER FOR PODDED DESIGN (LFRJ) ROLL & WELD CONSTRUCTION
  - B-1-4 CHAMBER FOR AFT INLET DESIGN (SFRJ)
    - B-1-4-1 ROLL AND WELD CONSTRUCTION
    - B-1-4-2 DEEP DRAW CONSTRUCTION
    - B-1-4-3 MACHINED AND SHEAR SPUN CONSTRUCTION
  - B-1-5 CHAMBER FOR AFT INLET DESIGN (SFDR OR LFDR)
    - B-1-5-1 ROLL AND WELD CONSTRUCTION
    - B-1-5-2 DEEP DRAW CONSTRUCTION
    - B-1-5-3 MACHINED AND SHEAR SPUN CONSTRUCTION
- B-2 BOOSTER CHAMBER ASSEMBLY (FOR NON-INTEGRAL BOOSTER ONLY)
  - B-2-1 STAGED (SEPARABLE)
    - B-2-1-1 ROLL AND WELD CONSTRUCTION
    - B-2-1-2 DEEP DRAW CONSTRUCTION
  - B-2-2 NON-STAGED

TABLE 1 (CONT.)

B-2-2-1 ROLL AND WELD CONSTRUCTION
B-2-2-2 DEEP DRAW CONSTRUCTION
B-3 SUSTAINER NOZZLE ASSEMBLY
B-3-1 SILICA PHENOLIC INSERT
B-3-2 METALLIC/SILICA PHENOLIC
B-4 SUSTAINER IGNITER ASSEMBLY
B-4-1 LIQUID FUEL RAMJET IGNITER
B-4-1-1 EXTERNALLY LOCATED
B-4-1-2 INTERNALLY LOCATED
B-4-2 SOLID DUCTED ROCKET IGNITER
B-5 BOOSTER IGNITER ASSEMBLY
B-5-1 HEAD END IGNITER
B-5-2 NOZZLE MOUNTED IGNITER
B-6 BOOSTER PROPELLANT
B-6-1 PROPELLANT FOR INTEGRAL BOOSTER (SFRJ)
B-6-1-1 HTPB (HIGH SMOKE AND LOW SMOKE)
B-6-1-2 CTPB (HIGH SMOKE AND LOW SMOKE)
B-6-2 PROPELLANT FOR INTEGRAL BOOSTER (LFRJ, SFDR, LFDR)
B-6-2-1 HTPB (HIGH SMOKE AND LOW SMOKE)
B-6-2-2 CTPB (HIGH SMOKE AND LOW SMOKE)
B-6-3 PROPELLANT FOR NON-INTEGRAL BOOSTER
B-6-3-1 HTPB (HIGH SMOKE AND LOW SMOKE)
B-6-3-2 CTPB (HIGH SMOKE AND LOW SMOKE)
B-7 BOOSTER NOZZLE ASSEMBLY
B-7-1 NOZZLE FOR INTEGRAL DESIGN
B-7-1-1 SILICA PHENOLIC/GRAPHITE
B-7-1-2 SILICA PHENOLIC/METAL/GRAPHITE #1
B-7-1-3 SILICA PHENOLIC/METAL/GRAPHITE #2
B-7-1-4 INTEGRAL DESIGN - CONSUMABLE BOOSTER NOZZLE
B-7-2 NOZZLE FOR NON-INTEGRAL BOOSTER
B-7-2-1 SILICA PHENOLIC/METAL/GRAPHITE
B-7-2-2 CONSUMABLE BOOSTER NOZZLE
B-8 BOOSTER NOZZLE RETENTION ASSEMBLY (INTEGRAL)
B-8-1 BOOSTER NOZZLE RETENTION ASSEMBLY (INTEGRAL)
B-8-2 BOOSTER NOZZLE ATTACK CLAMP ASSEMBLY (INTEGRAL)
B-9 BOOSTER ATTACH CLAMP ASSEMBLY (NON-INTEGRAL)
B-10 DOME PORT COVER
B-11 CASE PORT COVER
B-12 AFT SHROUD (NON-INTEGRAL BOOSTER)
B-13 BOOSTER/COMBUSTOR OPTIONS
B-13-1 FIXED LAUNCH RAIL
B-13-2 EXTERNAL FOLDING LAUNCH LUG
B-13-3 FOLDING LAUNCH LUG/SWAY BRACE/FAIRING SUPPORT
B-13-4 360° & 180° SWAY BRACE OR SUPPORT
B-13-5 THERMAL INSULATION FOR IRR (LFRJ OR DR)
B-13-5-1 PTV VENTED
B-13-5-2 SRL VENTED
B-13-5-3 CONTINUOUS
B-13-6 THERMAL INSULATION (SFRJ)
B-13-6-1 VENTED
B-13-6-2 CONTINUOUS
B-13-7 STRONGBACK
B-13-8 IGNITER SAFE/ARM ASSEMBLY

TABLE 1 (CONT.)

SUSTAINER FUEL SYSTEM (LIQUID)
C-1 SUSTAINER FUEL - LFRJ
    C-1-1 JP-5
    C-1-2 SHELLDYNE
    C-1-3 TH DIMER
    C-1-4 SI-80
C-2 SUSTAINER FUEL - LFDR
    C-2-1 UDMH
    C-2-2 HYDRAZINE
    C-2-3 MMH
C-3 SUSTAINER OXIDIZER - LFDR
    C-3-1 IRFNA
    C-3-2 NITROGEN TETROXIDE
C-4 FUEL TANK - LFRJ
    C-4-1 FUEL TANK WITH STANDPIPE AND FULL BLADDER
        C-4-1-1 ROLL AND WELD CONSTRUCTION
        C-4-1-2 DEEP DRAW CONSTRUCTION
        C-4-1-3 MACHINED FORGING WITH ROLL AND WELD CASE CONSTRUCTION
        C-4-1-4 MACHINED AND SHEAR SPUN CONSTRUCTION
    C-4-2 FUEL TANK WITH HALF ROLLING DIAPHRAGM
C-5 FUEL/OXIDIZER TANKS (LFDR) (REFER TO FUEL TANK SECTION C-4)
C-6 FUEL MANAGEMENT SYSTEM (LFRJ)
    C-6-1 FUEL DELIVERY SYSTEM
        C-6-1-1 TURBOPUMP
        C-6-1-2 SOLID PROPELLANT GAS GENERATOR
    C-6-2 FUEL CONTROL SYSTEM
        C-6-2-1 SINGLE AND MULTIPLE DISCRETE FUEL FLOW RATE CONTROL
        C-6-2-2 PNEUMATIC ALTITUDE SCHEDULED FUEL CONTROL
        C-6-2-3 FUEL/AIR RATIO CONTROL WITH PRESSURE RECOVERY AND MN LIMITERS
C-7 FUEL MANAGEMENT SYSTEM (LFDR)
C-8 FUEL MANIFOLDS AND INJECTORS
    C-8-1 WALL MOUNTED INJECTORS IN INLET PADS
    C-8-2 WALL MOUNTED INJECTORS AROUND INLET DUCT
    C-8-3 INTERNAL STREAM INJECTORS
    C-8-4 INTERNAL STREAM INJECTOR FOR PODDED RAMJET
C-9 FUEL MANAGEMENT SYSTEM COMPARTMENT
C-10 GAS GENERATOR - LFDR
C-11 GAS GENERATOR NOZZLE - LFDR
C-12 RAM AIR TURBINE SCOOP
C-13 FUEL SYSTEM OPTIONS
    C-13-1 FUEL TANK FIXED LAUNCH RAIL
    C-13-2 FUEL TANK EXTERNAL FOLDING LAUNCH LUG
    C-13-3 SUBMERGED FOLDING LAUNCH LUG AND TANK SWAY BRACE
    C-13-4 FMS COMPARTMENT SUBMERGED FOLDING LAUNCH LUG
    C-13-5 FUEL TANK FOLDING LAUNCH LUG/SWAY BRACE/FAIRING SUPPORT
    C-13-6 360° & 180° SWAY BRACE OR SUPPORT
    C-13-7 FUEL TANK STRONGBACK
    C-13-8 PODDED ENGINE MOUNT LUG
    C-13-9 EXTERNAL INSULATION
    C-13-10 WIRING & PLUMBING TUNNEL
SUSTAINER FUEL SYSTEM (SOLID)

TABLE 1 (CONT.)

D-1 FUEL - SFDR
    D-1-1 60% MAGNESIUM (CAST)
    C-1-2 60% MAGNESIUM (PRESSED)
D-2 FUEL - SFRJ
    D-2-1 UT-18818 (LOW SMOKE)
    D-2-2 UT-146949 (HIGH SMOKE)
D-3 GAS GENERATOR CHAMBER ASSEMBLY (SFDR)
    D-3-1 ROLL AND WELD CONSTRUCTION
    D-3-2 DEEP DRAW CONSTRUCTION
    D-3-3 MACHINED AND SHEAR SPUN CONSTRUCTION
D-4 SOLID DUCTED ROCKET NOZZLE ASSEMBLY
D-5 SOLID DUCTED ROCKET SYSTEM OPTIONS
    D-5-1 FIXED LAUNCH RAIL
    D-5-2 EXTERNAL FOLDING LAUNCH LUG
    D-5-3 FOLDING LAUNCH LUG/SWAY BRACE/FAIRING SUPPORT
    D-5-4 360° & 180° SWAY BRACE OR SUPPORT
    D-5-5 STRONGBACK
FINAL ASSEMBLY
E-1 LIQUID FUEL RAMJET - INTEGRAL ROCKET - RAMJET
E-2 LIQUID FUEL RAMJET - STAGED BOOSTER
E-3 LIQUID FUEL RAMJET - PODDED
E-4 SOLID FUEL RAMJET - INTEGRAL ROCKET - RAMJET
E-5 SOLID FUEL DUCTED ROCKET - INTEGRAL ROCKET - RAMJET
E-6 SOLID FUEL DUCTED ROCKET - STAGED BOOSTER
E-7 LIQUID FUEL DUCTED ROCKET - INTEGRAL ROCKET - RAMJET
E-8 LIQUID FUEL DUCTED ROCKET - STAGED BOOSTER

The nature of the product implies that the contractor will be a major aerospace manufacturer. Ramjet engines are not in the same category of manufacturing as turbine engines; therefore, it cannot be automatically assumed that the prime contractor would be limited to companies which have specialized turbine-engine manufacturing facilities. Ramjets, by their very nature, are fairly simple devices which are capable of manufacture by almost any airframe, engine or propulsion system company.

Most aerospace companies have a myriad of special fabrication equipment and capabilities; therefore, it is difficult to project the difference in manufacturing cost between company "A" and company "B". In order that the program not bog down in trying to establish which company is best equipped to manufacture which component, the manufacturing capabilities of the Vought Corporation are assumed "representative" of the aerospace industry. This assumption permits the cost estimating for this program to be done in the same way Vought estimates any other production job.

These basic ground-rules were used to estimate costs for the baseline components reported here and in the cost handbook. Detail estimates on those components that Vought normally manufactures were obtained from qualified departmental estimating specialists who, in most cases, had experience on the ALVRJ program.

Estimates for special hardware or materials such as castings or forgings that are produced by specialty firms were obtained from vendors or from standard costing catalogues and price lists.

Costs for subcontracted services such as propellant loading of boosters, solid propellant gas generators, solid fuel ramjets and solid ducted rockets were obtained through subcontracts. Costs for these services for a range of sizes and quantities were subcontracted to Chemical Systems Division of United Technologies (Sunnyvale) and Rocketdyne Division of Rockwell International (McGregor).

Cost estimates for special equipment or systems that would not typically be manufactured by Vought were obtained through direct contact with potential vendors, from prior cost quotes on similar programs, and from personal contact with individuals having experience in the areas in question. These are discussed later in the appropriate areas.

The following sections will describe the detail procedures and assumptions that were used to generate costs that are presented.

a. Production Cost Elements

There are many people and organizations involved in the manufacture and delivery of a product like a ramjet engine. Each person and organization has a specific function to perform to insure that the delivered product meets the requirements of the customer, but the costs for each function are accumulated and charged in different ways. In setting up a cost prediction methodology these elements of cost must be taken into account and their sensitivity to program variables must be determined.

In a broad sense, costs can be categorized by Direct and Indirect and by Recurring and Non-Recurring. A general matrix of major cost elements within these categories can be illustrated in the following figure.

	DIRECT	INDIRECT
NON-RECURRING	o Design o Development o Test o Production Tooling	o Labor Overhead o Material Overhead o General and Administrative
RECURRING	o Manufacturing Labor o Materials o Support Services	o Labor Overhead o Material Overhead o G & A

FIGURE 13 COST ELEMENT MATRIX

Direct costs are those costs which are uniquely and specifically associated with the product being manufactured. Indirect costs are those general costs associated with the company's doing business and are shared by all programs as a percentage of some element or elements of the program's direct costs.

In developing a methodology for predicting production costs of ramjets all elements of cost must be considered; however, only a few of them have major significance. These are <u>production tooling</u>, <u>manufacturing labor</u> and <u>materials</u>. Note that the tooling costs are in the non-recurring category whereas the labor and materials are recurring. The approach to estimating each of these three elements of cost is discussed in the following sections. The application of the appropriate percentage factors for the other cost elements (both direct and indirect) is also discussed in the section on dollarizing the estimates.

A summary of all of the cost estimates for the baseline components is included in Appendix 1. The tables in Appendix 1 are separated into components typically manufactured by the prime engine contractor (Tables 1-1, 1-2, and 1-3 for the three main structural materials); components and services that would typically be subcontracted such as thermal insulation and booster propellant loading (Table 1-4); and finally, those components that would typically be purchased like fuel controls, igniters and pumps (Table 1-5).

(1) Manufacturing Labor Estimating

The methodology developed for this program was designed to handle both non-recurring and recurring costs associated with the fabrication of every component, sub-component and part defined in the baseline system. Recurring costs are those incurred by all departments for their repetitive and sustaining effort associated with and in support of the serial manufacture

of a part. Non-recurring costs are those incurred only once during the manufacturing cycle and are associated with program costs rather than part cost. Figure 14 illustrates the recurring cost breakdown.

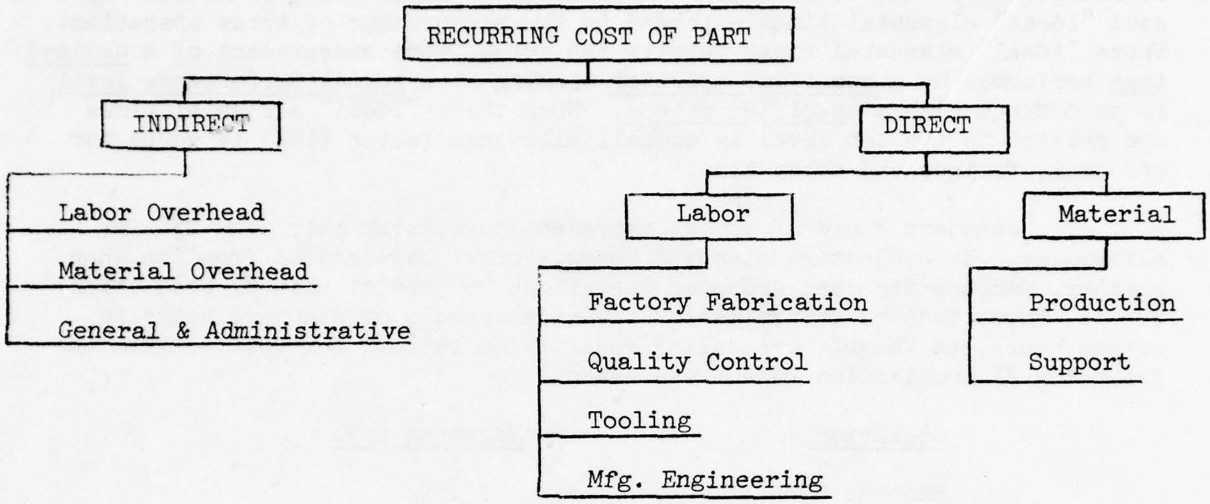


FIGURE 14 RECURRING COST BREAKDOWN

Factory fabrication labor is the direct effort required to transform production raw material into the final part or component. The cost estimating technique used at Vought utilizes Industrial Engineering standard equations to calculate the pure labor standard hours associated with the detail fabrication operations performed in the manufacture and/or assembly of a part. These standard hours not only account for the basic work content of a task but allow for other elements which are part of factory labor such as fatigue, waiting time for tools and materials, attention to personal needs, etc. Figure 15 depicts the Vought "Standard Hour".

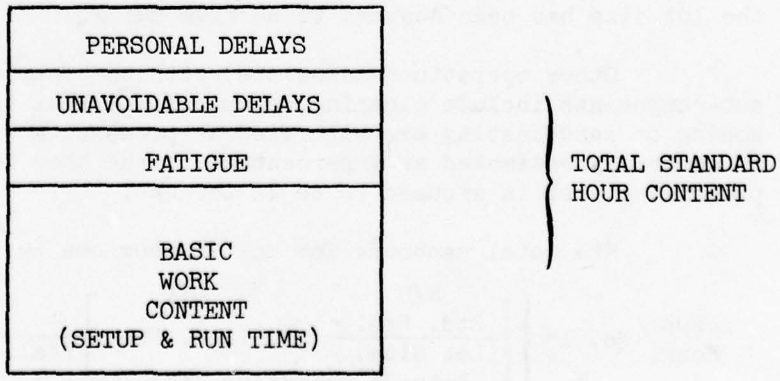


FIGURE 15 ELEMENTS OF FACTORY LABOR

The Industrial Engineering time standards at Vought were developed by Industrial Engineers through repetitive "stop watch" observation of individual elements required in machining, forming, assembly and checkout operations. This standard hour data system has been used in manufacturing for approximately twenty (20) years and is updated continuously for the effect of new equipment and techniques. The Industrial Engineering standards represent "ideal" elemental times expended in the performance of these operations. These "ideal" elemental times involve the actual time measurement of a <u>defined task</u> performed by a <u>qualified operator</u> working at a <u>normal performance level</u> in accordance with a <u>specified method</u>. When these "ideal" elemental times are related to the job level an overall allowance factor (15%) is added for personal, fatigue and delay time.

Standard hours at Vought represent pure labor only plus 15% for allowances. In projecting standard hours, Vought has derived from its shop history, factors for each group of operations to predict unit #1 production costs. These factors determined by the relationship of standard hours to actual hours, at Vought, are called realization rates. For this program the following #1 realization rates were used:

Operation	Realization @ #1
Machine Shop	17.5%
Sheet Metal	17.5%
Welding	12.0%
Bonding	12.0%
Assembly	12.0%
Paint	10.0%

The manhours for unit number one would be computed using the relationship

$$\text{Actual Hours No. 1} = \frac{\text{Standard Hours}}{\text{Realization Rate}} .$$

Every operation is normally estimated by set-up time which is the time associated with placing the work piece in a tool and making the proper adjustment prior to the operation and by operating time which is the actual cutting or drilling operation associated with each work piece. Set-up time is normally prorated over a number of units being worked. In this program the lot size has been assumed to be five units.

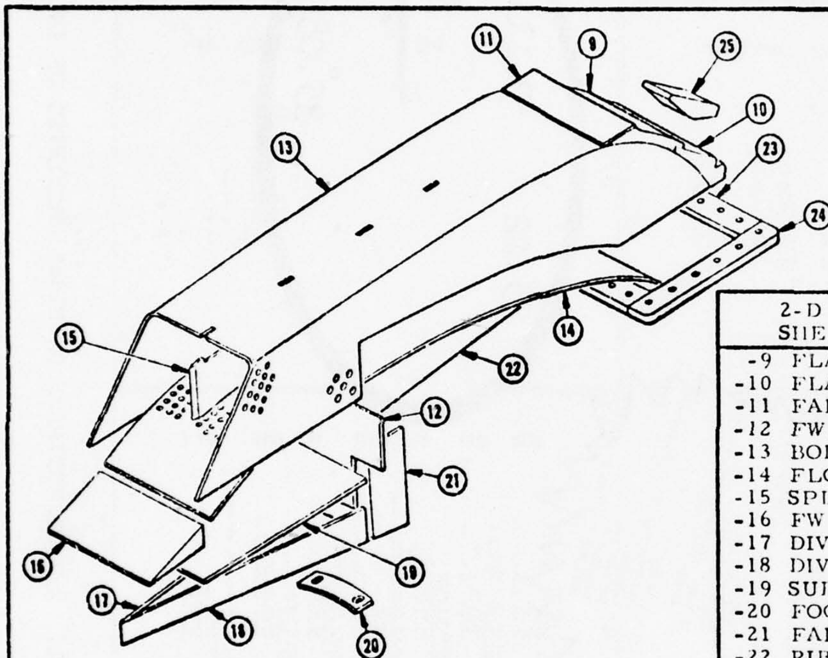
Other operations associated with the fabrication of the parts and sub-components include cleaning, chemical and heat treat, coating, plating; honing or sandblasting are signified as processing costs. Processing labor is generally estimated as a percentage of the shop labor. In this program, processing cost is assumed to be 12 percent.

The total manhours for unit number one is determined by the formula:

$$\begin{matrix}\text{Actual} \\ \text{Hours}\end{matrix} \text{ No. 1} = \left\{ \underbrace{\left[\overset{S/U}{\frac{(\text{Std. Hrs.})}{(\text{Lot Size})}} + \overset{O/T}{(\text{Std. Hrs.})} \right]}_{\substack{\text{Setup + Operating Time, Unit 1} \\ \longleftrightarrow \\ (S/U + O/T)}} \frac{1}{\text{Realization}} \right\} \times (S/U+O/T) \frac{\text{Processing \%}}{100}$$

To illustrate how the estimate of standard hours was used to estimate manufacturing labor costs on this program, the following example is provided.

Figure 16 shows a sketch of a 2-dimensional aft inlet assembly (component A-1-2). A listing of the components parts is shown on the figure. Detail estimates were made on each part and sub-component assembly for every operation associated with the fabrication of the c.mponent.



2-D AFT INLET ASSEMBLY
SHEET METAL CONSTRUCTION

- -9 FLANGE
- -10 FLANGE
- -11 FAIRING INTERFACE
- -12 FWD SUPPORT
- -13 BODY
- -14 FLOOR
- -15 SPLITTER
- -16 FWD RAMP
- -17 DIVERTER
- -18 DIVERTER
- -19 SUBFLOOR
- -20 FOOT
- -21 FAIRING CLIP
- -22 RIB
- -23 AFT FLANGE
- -24 BASE FLANGE
- -25 BOSS
- -26 HELICOIL INSERTS (NOT SHOWN
- -26 AFT FAIRING ATTACH HARDWARE
- -27 (NOT SHOWN)
- -28 INLET INSTALLATION HARDWARE (NOT SHOWN)

FIGURE 16 2-D AFT INLET ASSEMBLY - SHEET METAL CONSTRUCTION

To show the magnitude of the estimating job, Figure 17 illustrates the amount of work associated with generation of the machining operation estimates for one of the sub-component operations. A summary of the complete standard hour estimates is shown in Table 2. Note that the hours are divided into set-up and operating time for each of the four different shop operations.

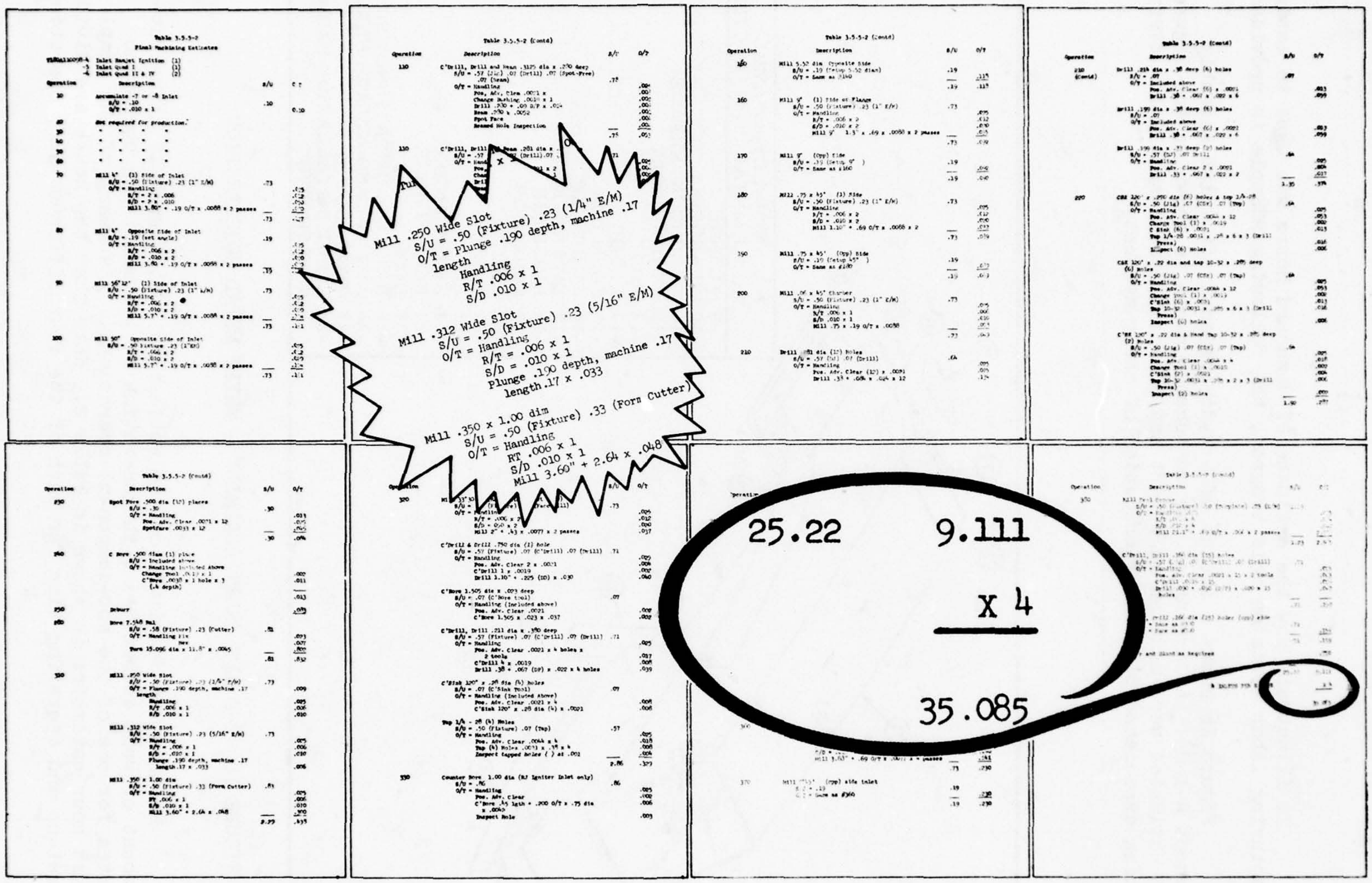


FIGURE 17 DETAIL ESTIMATE ON FINAL MACHINING OF INLET ASSEMBLY

TABLE 2

MANHOUR SUMMARY - STANDARD HOURS
17-4 PH SHEET METAL INLET

Part Number	Description	Ship Qty	Machine Shop S/U	Machine Shop O/T	Sheet Metal Shop S/U	Sheet Metal Shop O/T	Bonding Shop S/U	Bonding Shop O/T	Weld Shop S/U	Weld Shop O/T	Assembly S/U	Assembly O/T
T180A110098-9	Flange	4			.47	.284						
T180A110098-10	Flange	4			.47	.300						
T180A110098-11	Fairing	4			.52	.824						
T180A110098-12	Forward Support	4			.47	.400			.17	.212		
T180A110098-13	Body	4			1.27	3.472			.55	2.120		
T180A110098-14	Floor	4			.70	3.312						
T180A110098-15	Splitter	4			.38	1.816						
T180A110098-16	Forward Ramp	4	4.40	5.292								
T180A110098-14-500	Floor Splitter Weld Assembly	4							.55	2.624		
T180A110098-17	Diverter	4			.13	.200						
T180A110098-18	Diverter	4			.13	.200						
T180A110098-19	Sub-Floor	4			.13	.200						
T180A110098-20	Foot	4			.28	.264						
T180A110098-21	Fairing Clip	8			.44	.448						
T180A110098-19-500	Sub-Floor, Diverter W/A	4							.25	7.092		
T180A110098-22	Rib	4			.13	.200						
T180A110098-23	Aft Flange	4	4.80	5.000								
T180A110098-24	Base Flange	4	5.38	9.244								
T180A110098-25	Boss (Igniter)	1	2.62	.628								
T180A110098-7-500 -8-500	Inlet Weldment Inlet Weldment	4							1.62	7.000		
T180A110098-7 -8	Inlet Weldment Inlet Weldment	4							.25	4.341		
T180A110098-4 -5 -6	Inlet RJ Igniter Inlet Quad Igniter Inlet Quad II & IV	4	25.22	35.085								
T180A110098-1 -2 -3	Inlet Assy-RJ Igniter Inlet Assy-Quad I Inlet Assy-Quad II & IV	4									-	1.412
TOTALS			42.42	55.249	5.62	11.920	0	0	3.39	23.389	0	1.412

The total machine shop hours at unit No. 1 are estimated to be:

$$\left[\left(\frac{42.42}{5}\right)+(55.249)\right]\frac{1}{.175} \quad x\ (1.12) = 407.89$$

Similarly, the sheet metal shop hours at unit No. 1 are calculated:

$$\left[\left(\frac{5.62}{5}\right)+(11.920)\right]\frac{1}{.175} \quad x\ (1.12) = 83.48$$

The weld shop hours are calculated:

$$\left[\left(\frac{3.39}{5}\right)+(23.389)\right]\frac{1}{.12} \quad x\ (1.12) = 224.62$$

And finally the component assembly hours:

$$\left[\left(\frac{0}{5}\right)+(1.412)\right]\frac{1}{.12} \quad x\ (1.0) = 11.77$$

The total shop manhours for fabrication of the first inlet assembly is the sum of these four shop estimates; i.e., 727.76 manhours. These hours were based on four inlet assemblies per engine; therefore, the manhours per inlet would be 181.94.

Appendix 1 gives a complete listing of the total production manhours at unit number one for every component that was estimated in the program.

Developing estimates of factory labor hours at specified units of production other than #1 unit is accomplished by the application of an historically developed improvement curve sloped to the #1 unit costs. These improvement curves are derived through detail analysis of shop production cost data and include allowances for such things as operator familiarity with the job, engineering changes, lot size changes, tool adjustments, give and receive instructions and work stoppages due to part shortages. This projection of standard hours is illustrated on a log-log graph showing a cumulative average cost curve in Figure 18.

Below is a summary of the cost improvement curves used in developing the methodology for this program.

Units	Improvement Slopes
1-5	85%
6-100	80%
101-600	88%
601-2000	95%
2001&Sub.	98%

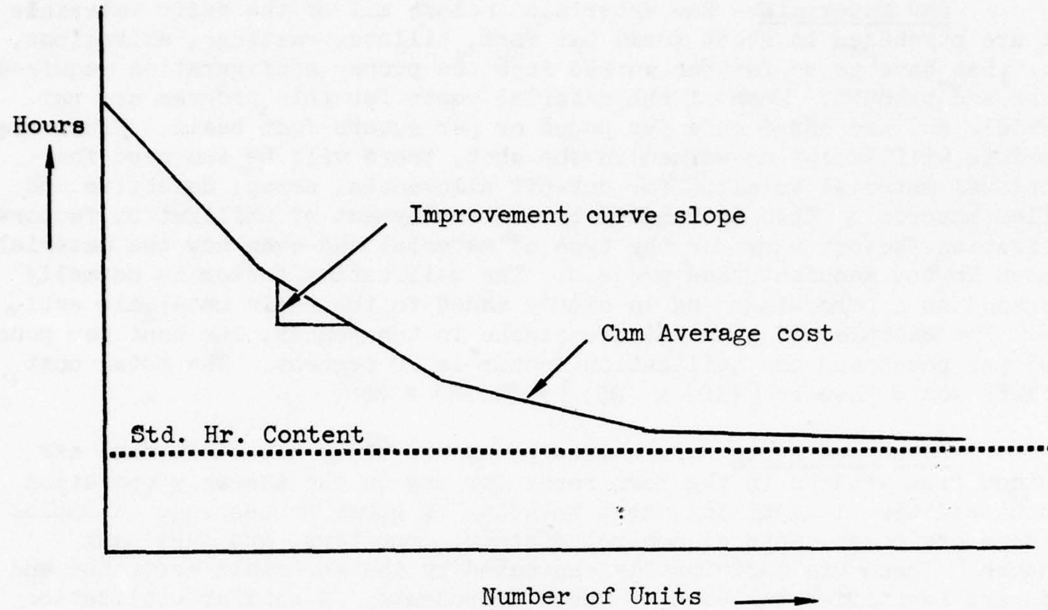


FIGURE 18 CUM AVERAGE COST

Cost estimating relationships have been developed in this program to estimate the labor hours for recurring support labor functions, i.e., quality control, tooling, manufacturing engineering, and graphic services. These sustaining support costs are incurred to maintain the normal production run. The activities required to support production may be briefly described as: maintain engineering drawings, perform material reviews, maintain production planning papers and quality control visual checklists, maintain the tools to include rework and replacement, provide blueprints to all work stations, perform receiving inspection of material, and process control and inspection of parts. For this program these support services were estimated at 30% of shop labor for inspection and quality assurance and 12% of shop labor for manufacturing engineering support. These manhours are assumed to be at a different labor rate than the manufacturing shop hours and are, therefore, dollarized separately. This is discussed in a later section of the report.

(2) Material Estimating

There are several major categories of materials cost that must be estimated. In broadly defined categories, these include:

(1) Raw materials
(2) Purchased parts
(3) Purchased labor (subcontracted services)
(4) Other (such as low cost purchased parts and shop supplies)

Raw Materials - Raw materials include all of the basic materials that are purchased in sheet form, bar form, billets, castings, extrusions, etc., that have to be further worked into the proper configuration required by the end product. Most of the material costs for this program are raw materials and are based on a per pound or per square foot basis. Since the materials will be cut or worked in the shop, there will be the need for additional material to allow for cut-off allowances, scrap, defective and spoiled material. This is handled by the employment of utilization factors. Utilization factors vary for the type of material and even how the material is used in the manufacturing process. The utilization factor is normally expressed as a percentage and is simply added to the basic materials estimate. For example, if a material estimate is ten pounds, the cost per pound is \$5 per pound and the utilization factor is 20 percent. The total cost estimate would then be $[(10) \times (\$5)] \times (1.20) = \$60$.

Purchased Parts - Purchased parts are those materials that are obtained from vendors in the form ready for use in the assembly operation without additional machining, heat treating or other processing. Examples of these are pumps, motors, control systems, computers, and fuel tank bladders. These are individually estimated by the materials estimator and costs are identified for each of these components. A similar utilization factor is employed for these components to account for breakage, repair or replacement.

Purchased Labor - Purchased labor or subcontracted services are also considered as a materials cost since they are administered through subcontracts or purchase orders in much the same way as raw materials and other services required in the manufacture of a product. The subcontracted services are normally those tasks which the company cannot do itself because of lack of experience or facilities, or it may be something that can be done cheaper by someone else. An example of a subcontracted service or purchased labor item for this program is the installation of the DC-93-104 thermal insulation and the booster propellant in the booster/combustor chamber. This kind of operation requires special facilities and techniques which are more appropriate for rocket motor manufacturing companies. Estimates for purchased labor are normally based on firm cost quotes form subcontractors. In this program, most of the purchased labor costs were estimated by two rocket-motor manufacturing firms. Their work is discussed in a subsequent section.

The type of materials cost estimating done for this program is illustrated in the following example:

Figure 19 shows a sketch of the LFRJ fuel tank. On the figure are the dimensions assumed by the materials estimator to compute the material costs. A summary of his estimate can be seen in Table 3. Note that the bottom line on the materials estimate sheet has two numbers. The first number is a materials non-recurring cost for vendor tools. The second number represents the materials recurring cost.

A summary of the direct materials estimates for each component is provided in Appendix 1. The material costs are shown in two areas where

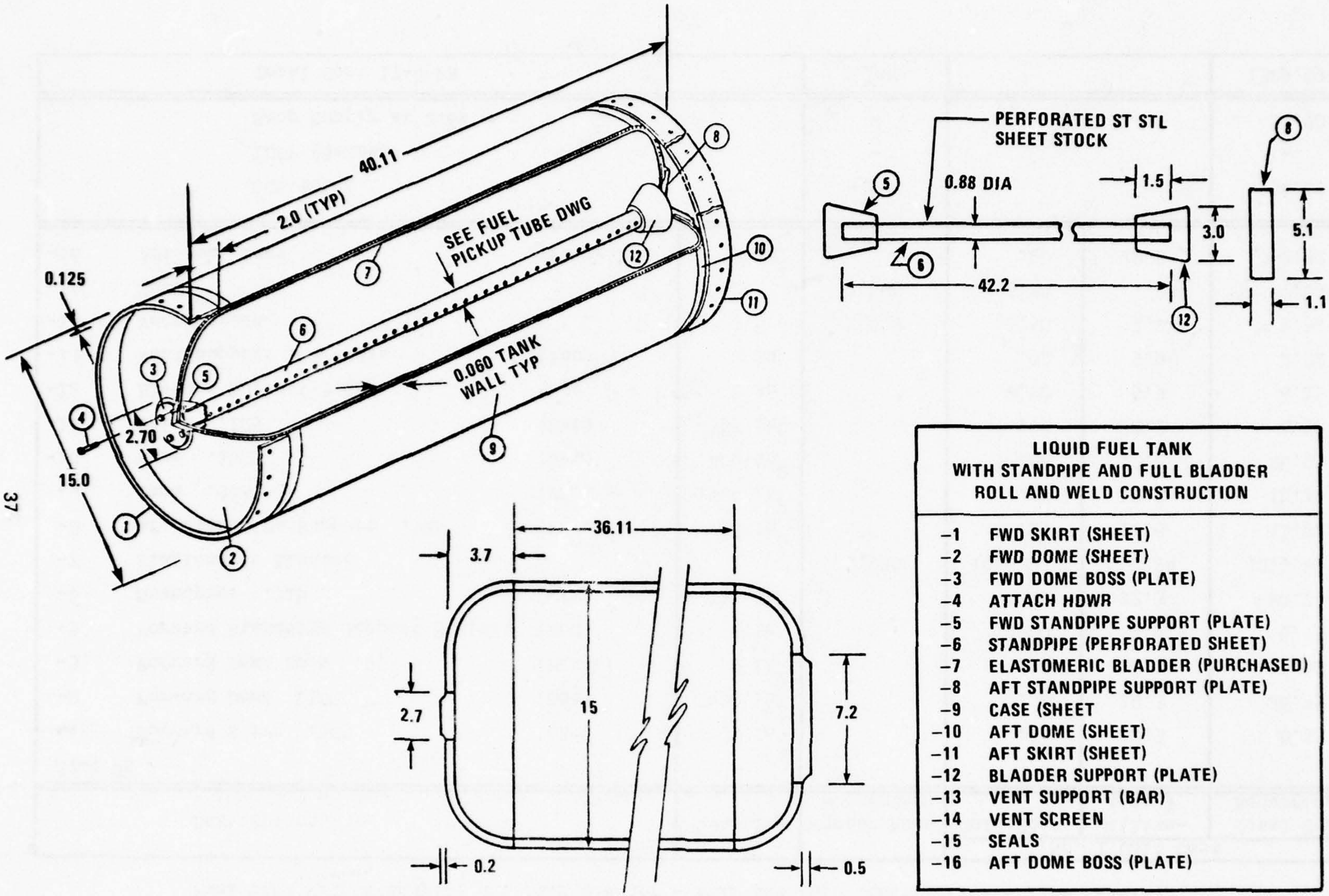


FIGURE 19 FUEL TANK WITH STANDPIPE AND FULL BLADDER - ROLL AND WELD CONSTRUCTION

TABLE 3

LIQUID FUEL RAMJET FUEL TANK

Fuel Tank with Standpipe and Full Bladder - Roll and Weld Construction - Item C-4-1-1

Description			Quantity	Vendor Non-Recurring	No. 1 Unit Cost		
					Unit Cost	Utiliza-tion %	Total Cost Recurring
17-4 PH							
-1	Forward S irt .125	(Sht)	95 in^2		.08	12.3	8.53
-2	Forward Dome .100	(Sht)	400 in^2		.06	12.3	26.95
-3	Forward Dome Boss .25	(Plate)	9 in^2		.20	12.3	2.02
-5	Forward Standpipe Support 3 dia.	(Rod)	2 in		2.80	9.9	6.15
-6	Standpipe .016	(Perf. Sht)	135 in^2		.15	12.3	22.74
-7	Elastomeric Bladder		1	5,900	1066.27	1.24	1079.49
-8	Aft Standpipe Support .500	(Plate)	36 in^2		.29	12.3	11.72
-9	Case .063	(Sht)	1744 in^2		.04	12.3	78.34
-10	Dome .100	(Sht)	400 in^2		.06	12.3	26.95
-11	Skirt .125	(Sht)	95 in^2		.08	12.3	8.53
-12	Bladder Support 3 dia.	(Rod)	2 in		2.80	9.9	6.15
-13	Vent Support 1 3/4 dia.	(Rod)	2 in		.92	9.9	2.02
-14	Vent Screen		1	1,500	7.50	1.24	7.59
-15	Seals		2	2,500	3.50	1.24	7.09
-16	Aft Dome Boss	(Plate)	9 in^2		.20	12.3	2.02
	Sub-Total			9,900			1296.29
	LCPP (delete)			-			-
	Shop Supply at 2.6%			-			33.70
	Total Cost 17-4 PH			9,900			1329.99

applicable. The non-recurring costs are shown in the column which is identified as tooling materials non-recurring and the recurring costs are shown as materials recurring.

(3) Tooling Estimating

The cost of tooling for a production program cannot be accurately determined until a firm manufacturing plan has been established and production sequences and schedules determined. Because none of these things can be fixed for a cost methodology program that covers a wide range of production variables, the tool costs are difficult to predict.

Tool estimating for this program was done recognizing full well that the tool costs vary over a considerable range when production quantities vary. An example of this can be illustrated in the comparison of a production program involving 50 engines and one involving 5000 engines. The smaller program is likely to employ what is sometimes referred to as "soft" tooling or tooling that is relatively inexpensive but is limited in the number of units it can produce. The large program would probably employ a higher grade of tooling and special fixtures which would cost more initially, but after amortization over a large number of units, would cost less on a per unit basis. Automation is also affected by the number of units to be produced. In very large quantity production, it is usually economically feasible to employ a higher degree of automation - computer operated machines, specially designed equipment, etc. In small production programs, the start-up cost would be prohibitive.

The procedure employed in this program is illustrated in the following example where a tooling estimate is made for a combustor chamber assembly, Figure 20.

As seen from the component description, there are nine detail parts (plus two sub-assembly tools) that had to be estimated. A separate estimate was prepared for each part. Table 4 shows the type of estimate that was made on one part, the forward dome (part, -2). There are several different labor costs, material costs and other direct charges normally associated with the detail estimate of tooling; therefore, the number of estimates that go into a single tool and the number of tools required for the fabrication of a single component using one material indicate that the tooling estimating job is a significant task.

A study of the tooling estimate reveals that the primary cost factor is tooling labor. Tooling materials and tooling direct charges are relatively small compared to labor costs and could have been neglected without introducing serious error. However, an approach was taken using a linear regression analysis to relate direct materials and direct charges to the manhour estimate so an expression could be found that would relate total tooling cost to one variable, manhours.

The direct material cost was found to be,

$$(\text{materials } \$) = 1.214 \times (\text{manhours}) - 288.55.$$

TABLE 4

MANUFACTURING ENGINEERING COST ESTIMATE

DATE 9-7-76

DESCRIPTION Liquid Fuel Ramjet - Aft Inlet Forward Dome (-104) - Booster/Combination Chamber Assembly, Roll and Weld 17-4PH

				MANHOURS
Prod. Planning	1	Part No's 5.3 Hrs. Each		5
N/C Programming		Tapes (See Tool List)		
Prod. Engr.	276	Tool Mfg. Hrs. at 7.1%		20
Work Control	25	Base Hours at 13%		3
Tool Design	1	Designs (See Tool List)		42
Mfg. Tech.	276	Tool Mfg. Hrs. at 2%		6
o Total Tool Engineering				76
o Total Tool Manufacturing	7	Tools (See Tool List)		276
oo Total Manufacturing Engineering				352
				DOLLARS
oo Total Tooling Material (See Tool List)			$	487
Other Direct Charges				
Computer Costs for N/C Programs			$	
Template Reproduction/Material Costs (36x1.399x1.19)			$	60
Prorated Items (To all Tool Categories)				
Freight & Express = $487 Material at $.0133			$	6
Other Misc. Costs 352 Hours at $.015			$	5
Trips ____ at $ ____ Each			$	
oo Total Other Direct Charge Dollars			$	71

The direct charges were found to be approximated by,

(direct charges, \$) = 0.040 x (manhours).

The dollarization of the tooling manhours is discussed in a later section of the report. A summary of the tooling manhour estimates for every component is provided in Appendix 1, column (3).

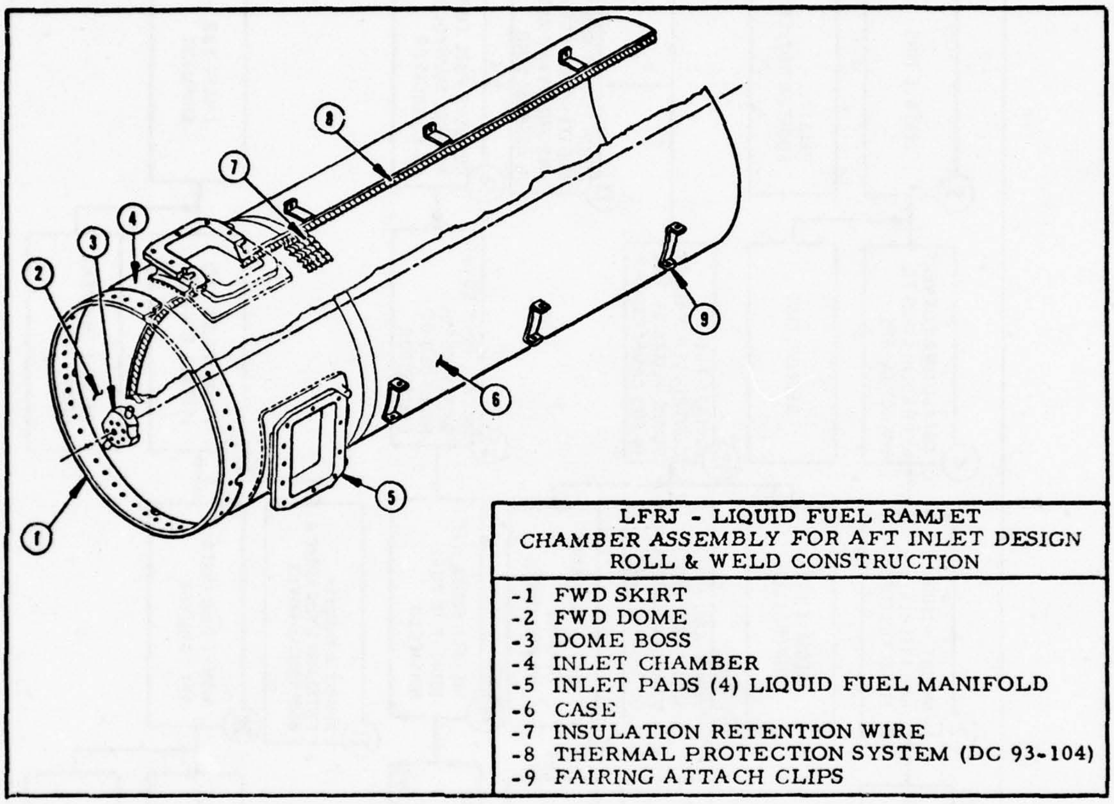


FIGURE 20 CHAMBER ASSEMBLY FOR LFRJ AFT INLET DESIGN - ROLL AND WELD CONSTRUCTION

b. Final Assembly Estimating

To estimate the final assembly costs it was necessary to define the final assembly operation for each of the ramjet assemblies. A flow chart showing each step of the assembly operations and the way each step interfaced with other assembly operations was constructed for each of the eight ramjet engines. Figure 21 shows the flow chart that was generated for the LFRJ-Integral Rocket/Ramjet. Most of the "action" blocks were denoted by a number which, to some extent, represented the sequence in which the assembly occurred. Each of the blocks was studied by the manufacturing and tooling estimators. A schematic of each of the steps was generated to get a better idea of the assembly operation. This is shown in Figure 22. Note that some of the assembly

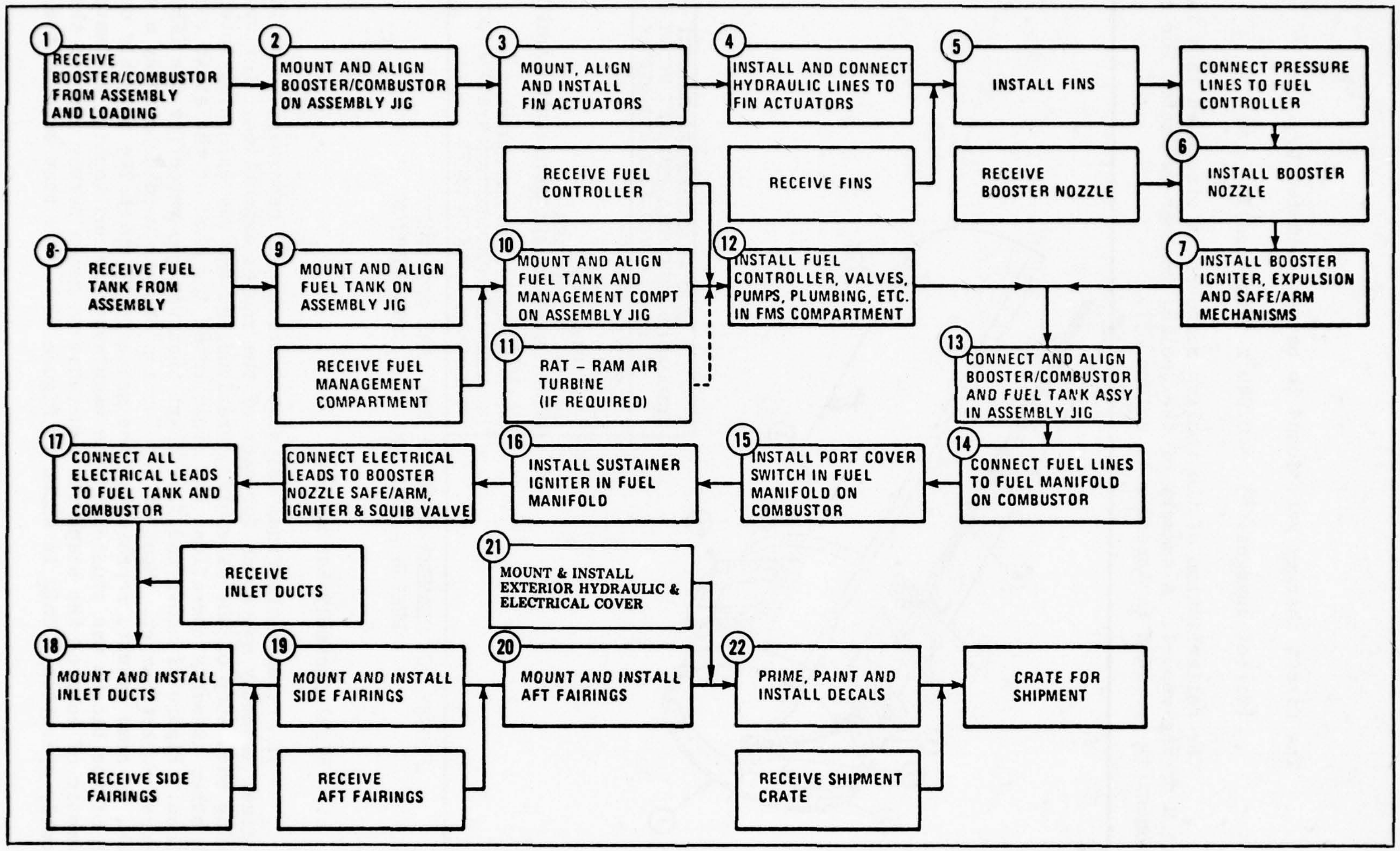


FIGURE 21 FINAL ASSEMBLY BLOCK DIAGRAM - LIQUID FUEL RAMJET - IRR

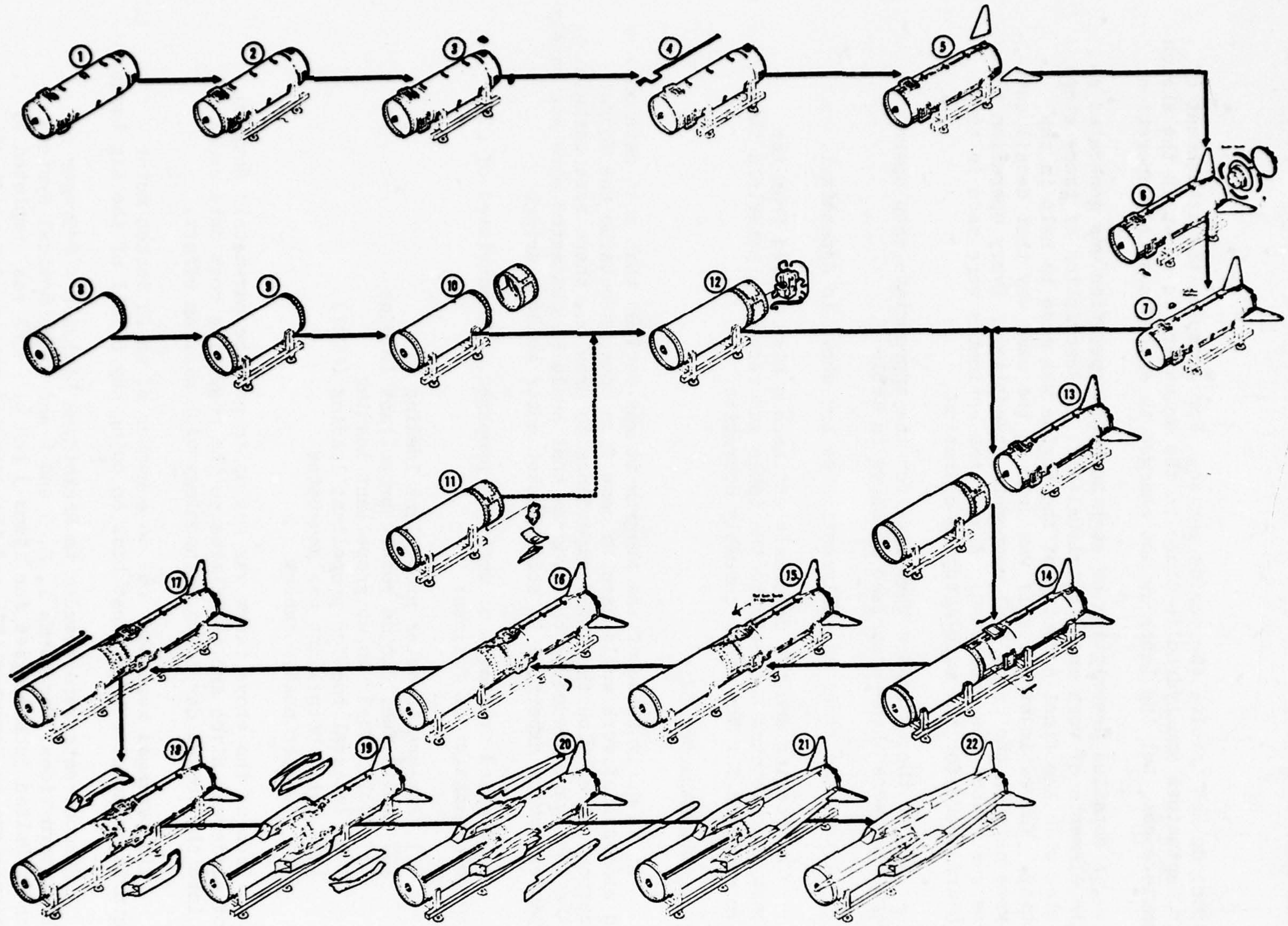


FIGURE 22 LIQUID FUEL RAMJET - IRR - FINAL ASSEMBLY

operations do not involve the engine per se. For example, the attachment of the fin actuators and hydraulic lines to the actuators is shown in the sketch for completeness, but the labor is not charged to engine assembly operation.

A detailed description of each assembly operation was generated so the main elements of work could be visualized. A description of those steps associated with the final assembly of the engine was made to help in the estimating. The estimating itself was done in the same way that detail estimates were made on the individual component assemblies. Every operation that involves some labor was estimated. Again, the estimates were made in terms of standard hours for the manufacturing operation.

All of the estimates were made for the appropriate shop operation. The operations were then summarized as shown in Table 5.

All of the final assembly estimates are shown in Appendix 1.

The tooling and the materials estimators also worked from the flow chart and sketches to estimate the tools and recurring materials that would be required for the final assembly operation.

c. Subcontractor Data

At an early phase of the program it was decided that cost data on certain elements of work would have to come from sources outside the Vought organization. Even with the ALVRJ experience to draw on, there were certain cost data that were needed by the program that could be estimated more accurately by companies having expertise in solid rocket motor manufacturing.

A proposed statement of work was prepared. It consisted of six separate work packages as follows:

(1) Integral booster propellant loading
(2) Solid fuel ducted rocket propellant loading
(3) Solid fuel ramjet propellant loading
(4) Integral booster propellant loading (SFRJ)
(5) Solid propellant gas generator
(6) Booster nozzle insert

Each of the above tasks was set up to produce parametric data on costs of different sizes and quantities so the resulting cost data could be worked into the Vought developed methodology with minimum effort.

Bid packages were sent out to a number of solid rocket motor manufacturing companies to request bids on doing any or all of the six tasks.

Subcontracts were awarded to Rocketdyne Division - McGregor of Rockwell International for items 1, 2, 5 and 6 and with Chemical Systems Division of United Technologies for items 3 and 4. Work was completed by both contractors in December 1976 and the data was submitted in a final report containing numerous tables, graphs and curves (References (4) and (5)). Because of the way costs were broken down in the methodology program, a number of follow-up discussions were held with both contractors to get a more

TABLE 5

Liquid Fuel Ramjet - IRR
Final Assembly 17-4PH
Manhour Summary

Part No.	Description	Ship Qty.	Tubing S/U	Tubing O/T	Assembly Shop S/U	Assembly Shop O/T	Electrical Shop S/U	Electrical Shop O/T	Paint Shop S/U	Paint Shop O/T
2	Mount & Align Booster Combustor on Assembly Jig	1			-	.232				
6	Install Booster Nozzle & Booster Igniter	1			-	.528				
7	Install Safe/Arm Mechanisms	1			-	.168	-	.300		
9	Mount & Align Fuel Tank on Assembly Jig	1			-	.232				
10	Mount FMS Compt. on Fuel Tank	1			-	1.102				
11	Install Ram Air Turbine & Ram Air Turbine Scoop	1			-	.404				
12	Install Fuel Controller, Valves, Pumps, Plumbing, Harness in FMS Compartment	1	-	.867	-	.929	-	1.000		
13	Connect & Align Booster/ Combustor & Fuel Tank Assembly in Assembly Jig	1			-	1.931				
14	Connect Fuel Lines to Manifold on Combustor	4	.30	.335	-	.416				
15	Install Port Cover Switch in Fuel Manifold on Combustor	1			-	.134				
16	Install Sustainer Igniter in Fuel Manifold	1			-	.134				
17	Connect All Electrical Leads to Fuel Tank & Combustor	1			-	.173	-	1.500		
18	Mount & Install Inlet Ducts	4			-	2.147				
19	Mount & Install Side Fairings	8			-	2.183				
20	Mount & Install Aft Fairings	4			-	2.340				
21	Install Exterior Hyd. &	1			-	.479				
22	Prime, Paint & Install Decals	1							-	1.926
	Totals (Std Hrs)		.30	1.202	0	13.532	0	2.800	0	1.926
	Realization Rates		17.5%	17.5%	12%	12%	12%	12%	12%	12%
	No. 1 Hrs		1.7	6.9	0	112.8	0	23.3	0	16.1

160.8 TOTAL

definitive breakdown on costs. Each contractor submitted supplemental reports of additional data which were very helpful in formulating the cost data needed in the program (References (6) and (7)). Because of the bulk of data in these reports, they have been submitted to the Air Force under separate cover rather than reproducing the data in this report. The final cost numbers from both contractors in the Vought format are, however, reported in Appendix 1. Table 1-4 contains most of the data. Some of it was integrated into some other components listed in Tables 1-1 through 1-3.

d. Other Cost Data

Many cost data were acquired through personal contact with individuals who have been involved with Vought on ramjet programs. In addition, a large number of costs quotes were previously obtained on the basic ALVRJ program as well as a number of proposed ALVRJ production programs that have been costed. A summary of some of these key contacts and type of cost data obtained is given in the following table.

TABLE 6

OTHER COST DATA

COMPANY	TYPE OF COST INFORMATION OBTAINED	PRIMARY SOURCE OF DATA
Marquardt	Fuel Controls, FMS Components	Manufacturer of hardware, Advanced concept studies
Marquardt	Podded Ramjet Components and Cost Data, Booster Nozzles	Ramjet Mfg.
Hamilton-Standard	FMS Components Turbopumps	FMS Manufacturing
Atlantic-Research	Nozzleless Rocket Motor	AFRPL sponsored studies
Garrett Corp.	FMS	Cost proposals on ALVRJ
Woodward	FMS	Cost proposals on ALVRJ
Boeing	Inlets	Air Force sponsored studies
Unidynamics	Igniters and other pyrotechnics	Igniter Mfg.

Unfortunately, much of the cost data obtained could not be broken into the three elements of cost that were needed for the cost methodology so the methodology was modified slightly to allow total cost data to be used.

An attempt was made to get as much background information on every estimate as possible so that quantity adjustment factors could be derived for the total cost data.

One of the main areas where there was a considerable spread in cost data was that of fuel management systems costs. For example, on the ALVRJ program, Vought requested cost quotes on a relatively simple fuel control system using an Ambient Pressure Controller. Cost quotes from four manufacturers varied by more than a factor of 10 for both small and large quantities. Although it was apparent that each of the suppliers had slightly different design approaches to the fuel control system, they were basically the same type of controller from a functional standpoint. The cost data were not broken down to such a level where the design-related cost drivers could be identified.

For purposes of the cost methodology, three types of fuel control systems are defined, each having at least two variations. A discussion of each type and the cost data follows:

Single and Stepped Flowrate - Figure 23 shows four variations of the Single and Stepped Flowrate Control Concepts -- the variations are in the number of "steps" of discrete flow rates provided.

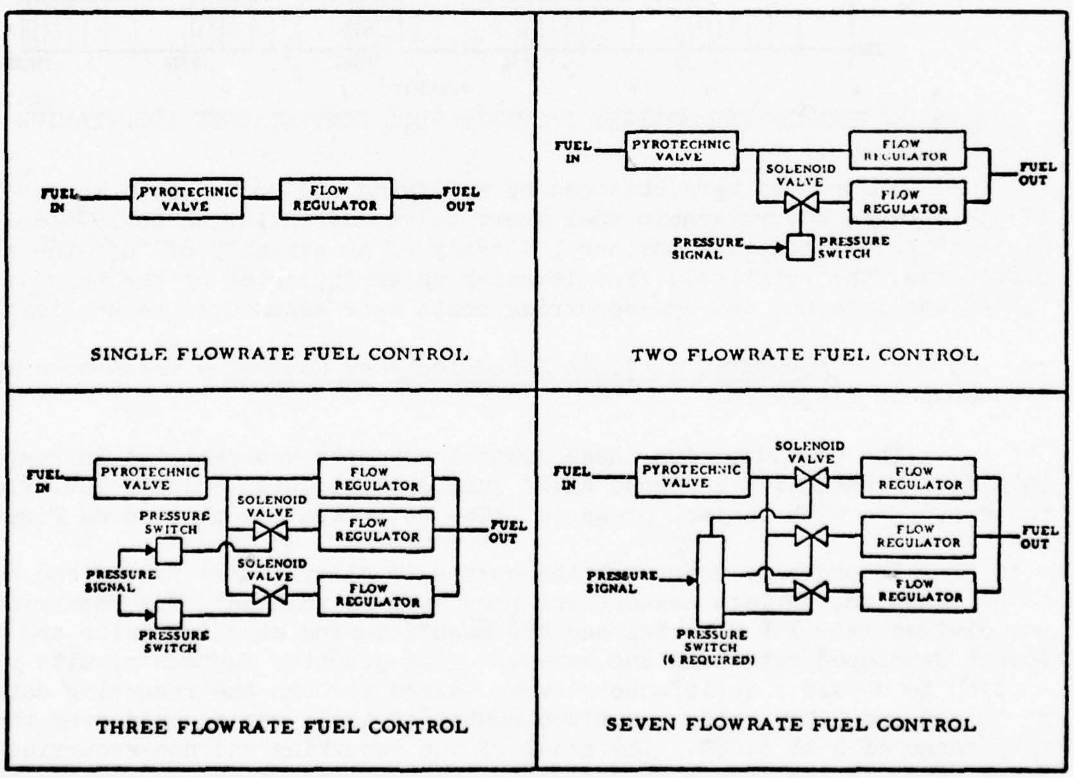


FIGURE 23 SINGLE AND STEPPED FLOWRATE FUEL CONTROLS

The cost data for the Single and Stepped Flowrate fuel controls are shown in Figure 24.

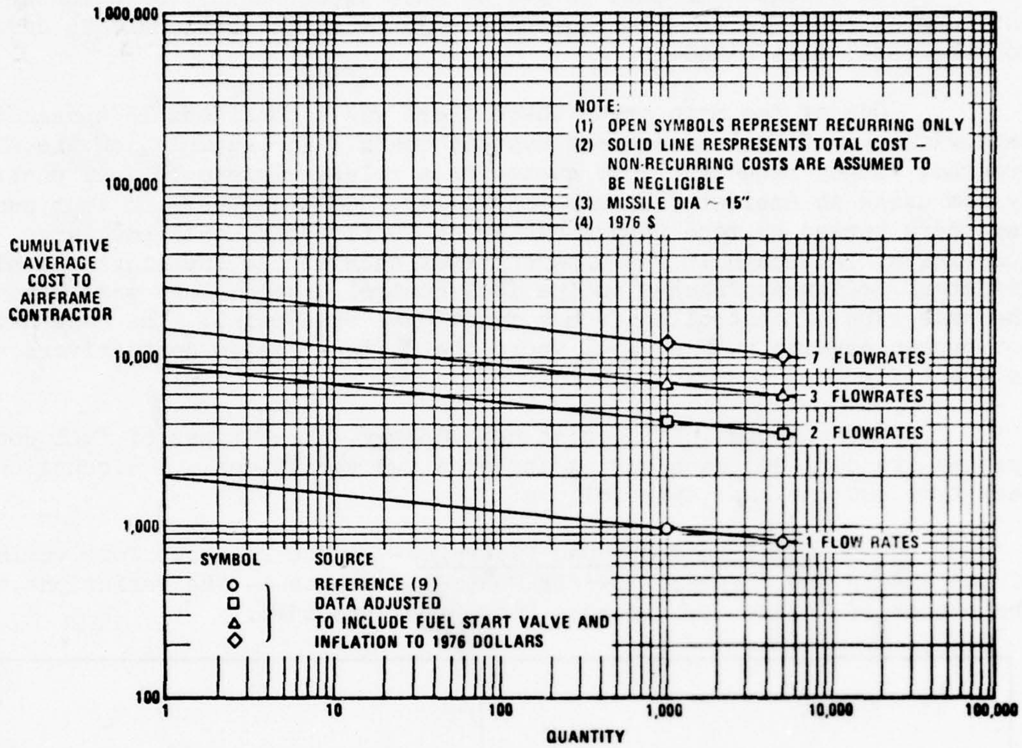


FIGURE 24 SINGLE AND STEPPED FLOWRATE FUEL CONTROL COST CORRELATION

These data were obtained by modifying the costs shown in reference (9) to include a pyrotechnic fuel start valve and inflation to 1976 dollars. Since this fuel control consists basically of an assembly of "off-the-shelf" components, the relatively flat learning curve indicated by the base data (~94%) was retained and non-recurring costs were assumed to be negligible.

Pneumatic Altitude Scheduled Fuel Control - These schematics are shown in Figure 25.

The cost data for these control concepts was received in response to a Vought RFP for a low cost ALVRJ fuel control which adjusts fuel flowrate in accordance with ambient pressure. The cost data are plotted on Figure 26.

In order to construct the curves to allow a unit number one cost to be computed, certain assumptions were made as follows: The recurring cost was divided into 15% material and 85% manufacturing at 2,000 units and the Vought developed materials and manufacturing quantity factors results were applied to obtain a satisfactory curve faired through the recurring data points at 30, 50 and 2,000 units. A fixed number of tools was assumed over the quantity range of 1 to 5,000. The total of the recurring and non-recurring costs represented in the figure by the solid line was determined by summing the elements at quantities 1, 10, 100, 500, 2,000, and 5,000. The "soft tooling"

data points also shown on the figure suggest that the cross over point at which production type tooling pays off is approximately 20 units.

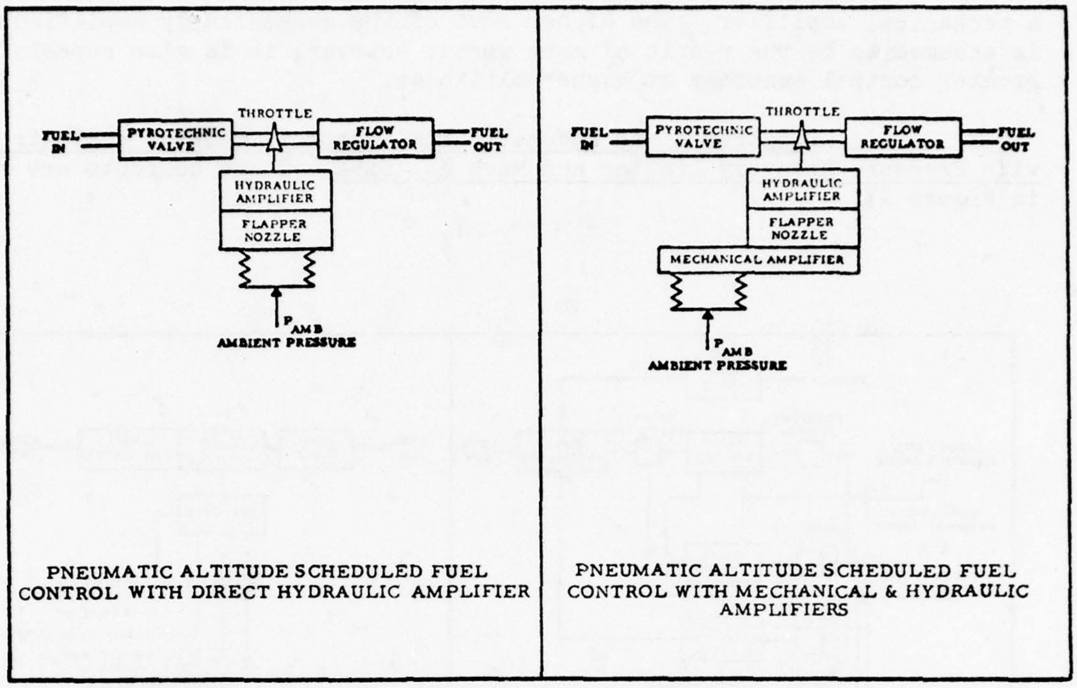


FIGURE 25 ALTITUDE SCHEDULED FUEL CONTROLS

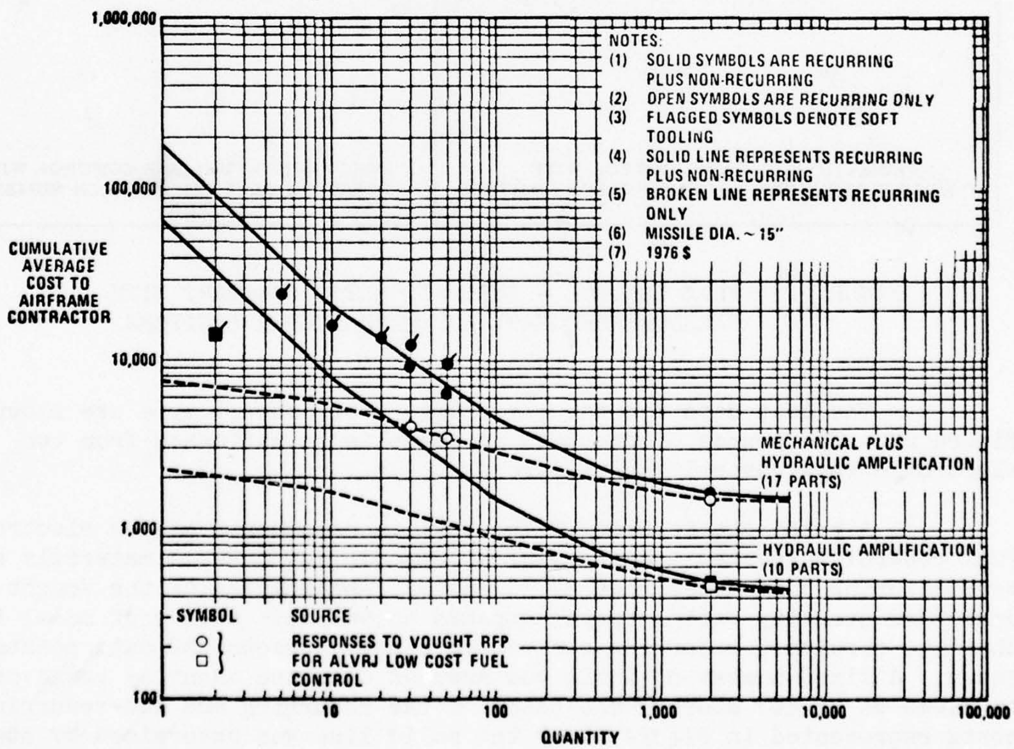


FIGURE 26 PNEUMATIC ALTITUDE SCHEDULED FUEL CONTROL COST CORRELATION

The basic difference in the two systems is that one system employs a mechanical amplifier. The higher cost of the mechanically amplified system is assumed to be the result of more parts; however, it is also capable of greater control accuracy at higher altitudes.

<u>Electronic and Pneumatic Fuel Control/Constant Fuel-Air Ratio with Pressure Recovery Limiter and Mach No. Bias</u> - These concepts are shown in Figure 27.

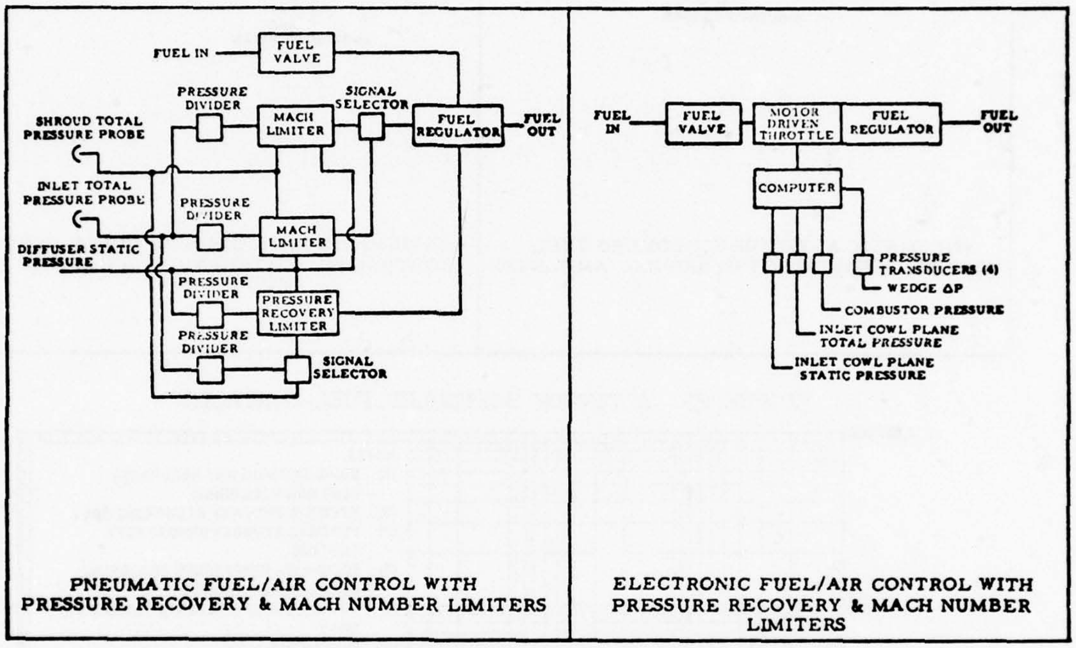


FIGURE 27 FUEL CONTROL - FUEL/AIR RATIO CONSTANT WITH PRESSURE RECOVERY AND MACH NUMBER LIMITERS

The cost data for the electronic fuel control type are shown in Figure 28. The source of the data is unpublished estimates from two electronic fuel control manufacturers.

A brief examination of the various components of the electronic fuel control suggested a cost model evenly divided between materials and manufacturing direct labor at 2,000 units. Application of the Vought developed quantity factor curves appears to validate this cost model in that the resultant recurring cost curve closely tracks the data points shown. A fixed number of tools was assumed over the quantity range of 1 to 5,000 as in (b) above. The total of the recurring and non-recurring costs represented in Figure 28 by the solid line was determined by summing the elements at quantities 1, 10, 100, 500, 2,000 and 5,000.

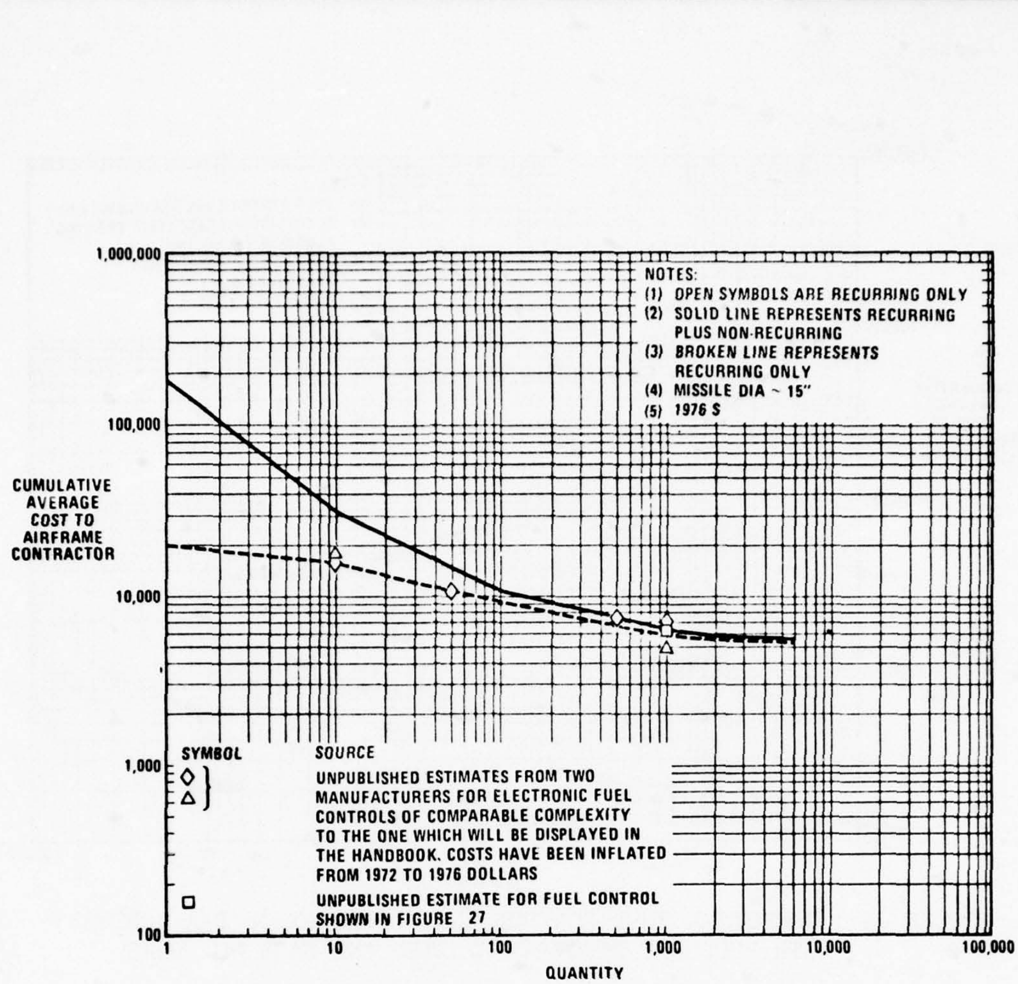


FIGURE 28 ELECTRONIC FUEL CONTROL COST CORRELATION
F/A CONSTANT WITH PRESSURE RECOVERY LIMITER
AND MACH NO. BIAS

The pneumatic fuel control performs essentially the same function as the electronic fuel control described above. The cost data shown in Figure 29 for this system were obtained from a recently completed TMC report addressing Modern Ramjet Engine (MRE) fuel control system component costs, reference (11).

In order to obtain the data points shown, adjustments were made to the base data to deflate from 1977 to 1976 dollars, include the industry average G&A and fee (24% and 10%), and include a prorated amount for assembly, acceptance testing, and crating. Extrapolation of the data to lower quantities was accomplished using the recurring and non-recurring quantity factor relations discussed previously.

<u>Fuel Control Cost Versus Size</u>: Due to the scarcity of data relating fuel control cost with missile size, the philosophy adopted initially was that cost would be independent of missile size. This situation was reevaluated and an attempt made to develop cost-size relationships. The results, updated to include fuel start valves in cases where such valves were not previously included, are shown in Figure 30.

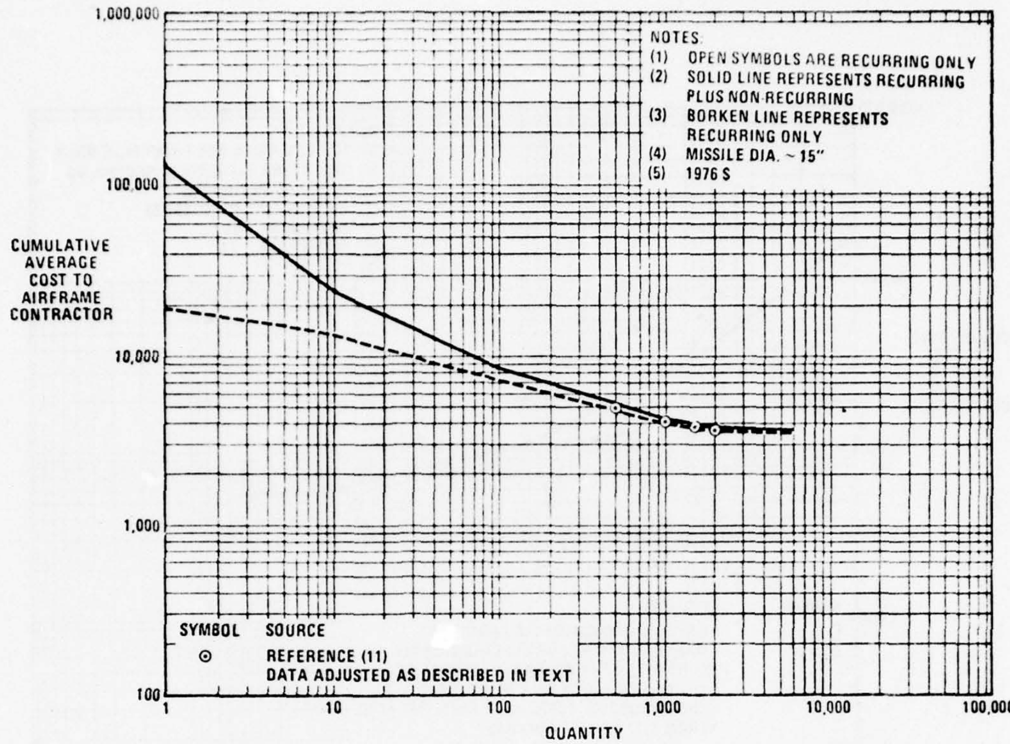


FIGURE 29 PNEUMATIC FUEL CONTROL COST CORRELATION F/A CONSTANT WITH PRESSURE RECOVERY LIMITER AND MACH NO. BIAS

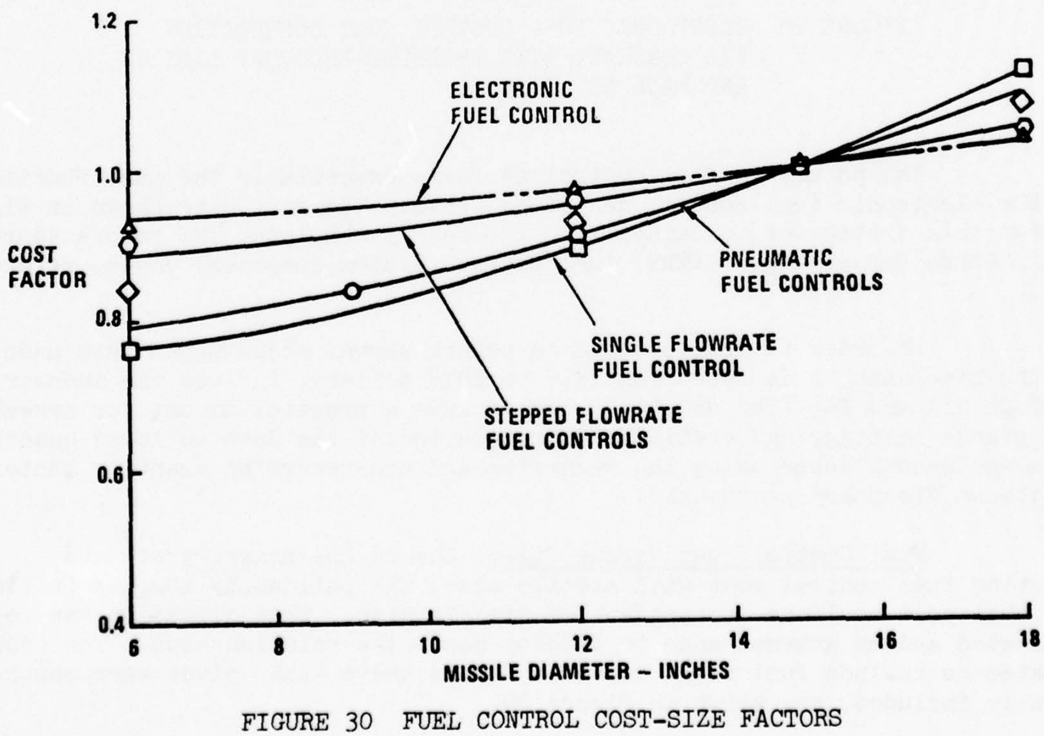


FIGURE 30 FUEL CONTROL COST-SIZE FACTORS

In summary, four different curves are presented which are intended to be applicable to the fuel control types considered. The GORJE pneumatic fuel control cost versus size data reported in reference (12) have been assumed to be representative of the various pneumatic fuel controls discussed above. The single flowrate and stepped flowrate fuel control data were calculated from information contained in reference (9). The various stepped flowrate fuel control estimates were averaged to yield a single cost-size curve. The electronic fuel control cost-size curve was developed assuming that the computer and pressure transducer costs are independent of missile size and the remainder of the system costs (i.e., fuel control and throttle valve) vary in the same manner as pneumatic fuel control costs.

Cost data for the turbopump were also obtained in much the same manner as the fuel controls. The turbopump, shown in Figure 31, is based on either a ram-air or gas driven turbopump.

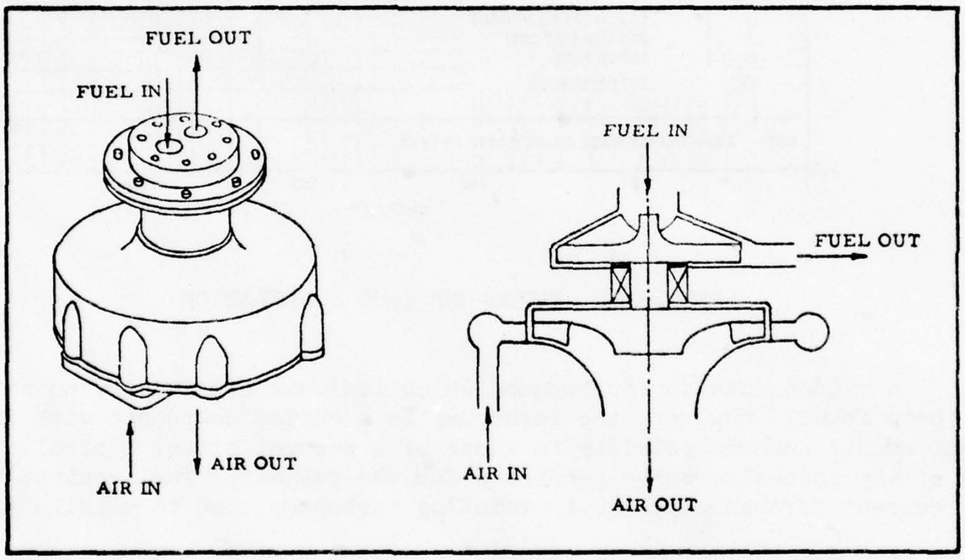


FIGURE 31 TURBOPUMP

Four data sources were obtained for turbopumps in various quantities. The costs have all been adjusted to represent mid-1976 rates as in the fuel control systems cost estimates. As indicated in Figure 32, three of the data sources were responses to a Vought request on an ALVRJ low cost turbopump development. The fourth source is from a recently completed TMC study addressing the MRE fuel management system costs. Since there is no apparent reason for the relatively large spread in the data, the cost handbook curves have been constructed to approximate an average of the data.

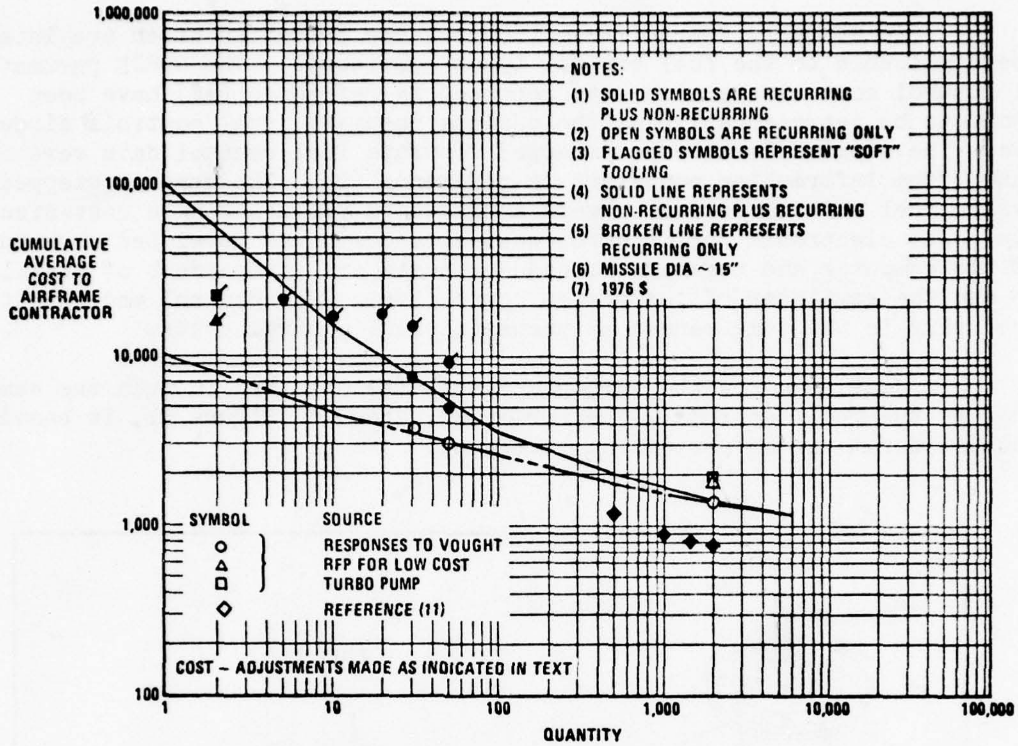


FIGURE 32 TURBOPUMP COST CORRELATION

Cost data for turbopumps which indicate sensitivity to size have not been found. However, the turbopump is a custom component with fabrication requirements somewhat similar to those of a pneumatic fuel control. Therefore, use of the cost-size curve generated for the pneumatic fuel control remains the current favored approach to relating turbopump cost to missile size.

e. Dollarizing The Estimates

One of the ground rules established at the beginning of the program was that the costs should be representative of Industry average cost. In order to generate true industry average costs, it would be necessary to have a large number of companies to independently estimate the costs of the entire list of components and all their variations. An alternate approach to this, and the one used here, is to take the manhour and direct materials dollar estimates and dollarize them using labor and overhead rates that are representative of the industry average.

Industry average labor and overhead rates were obtained through the Air Force Aeronautical Systems Division, Advanced Systems Cost Division, ASD/ACCS. The rates were based on taking several representative industrial organizations and their individual rates and numerically averaging them to arrive at a composite rate structure. Specific information on which companies

were used or how many were used in the composite was not provided. The rate structure is as follows:

Manufacturing Engineering Labor	$ 9.89/Hr.
Shop Labor	7.04/Hr.
Materials Handling Labor	6.69/Hr.
Quality Control Labor	7.73/Hr.
Manufacturing Overhead	140%
Material Overhead (Burden)	8%
General and Administrative	24%
Fee	10%

Although every Aerospace Company has a similar approach to costing, there are still basic differences in the way certain kinds of work are charged. Because of these variations, it is important that clarification is made on what functions and charges are assumed in this hypothetical production contract and where they are listed.

To assist in the build-up of the production costs, the ASPR was consulted to establish a format for pricing. DD Form 633, which is a general contract pricing form for DOD programs comes closest to outlining the cost elements of interest in this kind of production program. It is shown in Figure 33.

The methodology developed in this program segregates the costs of the ramjet assemblies, sub-assemblies and components into three basic cost elements: tooling, materials and manufacturing. Each of the three cost elements have certain parts that can be identified on the DD 633 form. Table 7 illustrates the relationship between the cost methodology cost elements assumed in this program and the standard pricing form.

A general formula for computing the total cost plus fee (TCPF) can be constructed from the DD 633 form as follows:

$$\underbrace{\left[\underbrace{\begin{bmatrix} (\text{Direct Materials}) \\ +(\text{Materials Overhead}) \\ +(\text{Direct Labor}) \\ +(\text{Labor Overhead}) \\ +(\text{Direct Costs}) \\ + \ldots\ldots \end{bmatrix}}_{\text{Total Direct Cost, TDC}} + \text{TDC} \times \frac{\text{G\&A\%}}{100}\right]}_{\text{Total Estimated Cost, TEC}} + [\text{TEC}] \times \frac{\text{Fee\%}}{100} = \text{TCPF}$$

Another way of writing it is:

$$[\text{TDC}] \left[1 + \frac{\text{G\&A\%}}{100}\right] \left[1 + \frac{\text{Fee\%}}{100}\right] = \text{TCPF}$$

With this general formula, the total cost plus fee can be computed for any elemental breakdown desired. For the tooling cost, for example, it could

DEPARTMENT OF DEFENSE

CONTRACT PRICING PROPOSAL

Form Approved
Budget Bureau No. 22-R100

This form is for use when submission of cost or pricing data (see *ASPR 3-807.3*) is required

PAGE NO.	NO. OF PAGES

NAME OF OFFEROR	SUPPLIES AND/OR SERVICES TO BE FURNISHED	
HOME OFFICE ADDRESS	QUANTITY	TOTAL AMOUNT OF PROPOSAL $
DIVISION(S) AND LOCATION(S) WHERE WORK IS TO BE PERFORMED		GOVERNMENT SOLICITATION NO.

COST ELEMENTS	PROPOSED CONTRACT ESTIMATE		
	TOTAL COST[1]	UNIT COST[2]	REFERENCE[3]
1. DIRECT MATERIAL[4] a. PURCHASED PARTS[5]			
b. SUBCONTRACTED ITEMS[6]			
c. OTHER MATERIAL (1) RAW MATERIAL[7]			
(2) STANDARD COMMERCIAL ITEMS[8]			
(3) INTERDIVISIONAL TRANSFERS *(at other than cost)*[9]			
2. MATERIAL OVERHEAD[10]			
3. INTERDIVISIONAL TRANSFERS AT COST[11]			
4. DIRECT ENGINEERING LABOR[12]			
5. ENGINEERING OVERHEAD[10]			
6. DIRECT MANUFACTURING LABOR[12]			
7. MANUFACTURING OVERHEAD[10]			
8. OTHER COSTS[13]			
9. *SUBTOTALS*			
10. GENERAL AND ADMINISTRATIVE EXPENSES[10]			
11. ROYALTIES[14]			
12. FEDERAL EXCISE TAX[15]			
13. *SUBTOTALS*			
14. PROFIT OR FEE			
15. **TOTAL PRICE** *(Amount)*			

I. HAVE THE DEPARTMENT OF DEFENSE, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION, OR THE ATOMIC ENERGY COMMISSION PERFORMED ANY REVIEW OF YOUR ACCOUNTS OR RECORDS IN CONNECTION WITH ANY OTHER GOVERNMENT PRIME CONTRACT OR SUBCONTRACT WITHIN THE PAST TWELVE MONTHS?

☐ YES ☐ NO *IF YES, IDENTIFY BELOW*

NAME AND ADDRESS OF REVIEWING OFFICE	TELEPHONE NUMBER

II. WILL YOU REQUIRE THE USE OF ANY GOVERNMENT PROPERTY IN THE PERFORMANCE OF THIS PROPOSED CONTRACT?

☐ YES ☐ NO *IF YES, IDENTIFY ON A SEPARATE PAGE.*

III. DO YOU REQUIRE GOVERNMENT CONTRACT FINANCING TO PERFORM THIS PROPOSED CONTRACT?

☐ YES ☐ NO *IF YES, IDENTIFY.* ☐ ADVANCE PAYMENTS ☐ PROGRESS PAYMENTS *OR* ☐ GUARANTEED LOANS

IV. HAVE YOU BEEN AWARDED ANY CONTRACTS OR SUBCONTRACTS FOR SIMILAR ITEMS WITHIN THE PAST THREE YEARS?

☐ YES ☐ NO *IF YES, SHOW CUSTOMER(S) AND CONTRACT NUMBERS BELOW OR ON A SEPARATE PAGE.*

V. DOES THIS COST SUMMARY CONFORM WITH THE COST PRINCIPLES SET FORTH IN ASPR, SECTION XV *(see 3-807.2(c)(2))*?

☐ YES ☐ NO *IF NO, EXPLAIN ON A SEPARATE PAGE*

This proposal is submitted for use in connection with and in response to ______________________ * and reflects our best estimates as of this date, in accordance with the Instructions to Offerors and the Footnotes which follow:

**DESCRIBE RFP, ETC.*

TYPED NAME AND TITLE		SIGNATURE
NAME OF FIRM		DATE OF SUBMISSION

DD FORM 1 APR 68 **633** PREVIOUS EDITIONS ARE OBSOLETE. S/N 0102-006-8102

FIGURE 33 DD PRICING FORM 633

TABLE 7
LOCATION OF KEY COST ELEMENTS IN METHODOLOGY

	TOOLING COST ELEMENTS	MATERIALS COST ELEMENTS	MANUFACTURING (LABOR) ELEMENTS
1. Direct Material			
a. Purchased Parts		Delivered hardware	
b. Subcontracted	Non-recurring by subs	Mtl used by subs	Labor by subs
c. Other			
1) Raw Material	Mtls for tool fab	Dir mtl used	
2) Freight/express		1% of Dir mtls	
2. Material Overhead (Burden)	Apply to all above (8%)	Apply to all above (8%)	Apply to all above (8%)
3. Interdivisional transfers at cost	n.a.	n.a.	n.a.
4. Direct engineering labor	n.a.	n.a.	n.a.
5. Engineering overhead	n.a.	n.a.	n.a.
6. Direct manuf labor			
a. Shop			Manhours x $7.04
b. Manuf Engineering	Manhours x $9.89		Manhours x $9.89
c. Quality			Manhours x $7.73
d. Materials Dept.		Manhours x $6.69	
7. Manufacturing Overhead	Apply to all labor above. (140%)	Apply to all labor above. (140%)	Apply to all labor above. (140%)
8. Other costs			
9. Total direct costs	Sum all elements above	Sum all elements above	Sum all elements above
10. General & Administrative	Apply to above (24%)	Apply to above (24%)	Apply to above (24%)
11. Royalties	n.a.	n.a.	n.a.
12. Federal Excise Tax	n.a.	n.a.	n.a.
13. Total Estimated Cost	Add (9) and (10)	Add (9) and (10)	Add (9) and (10)
14. Fee or Profit	Apply to (13) (10%)	Apply to (13) (10%)	Apply to (13) (10%)
15. Total Cost plus Fee	Add (13) to (14)	Add (13) to (14)	Add (13) to (14)

be computed by taking the sum of all elements in the direct cost matrix multiplying it by the two factors, (1 + G&A) and (1 + Fee). On this program, a constant value of G&A and Fee is used throughout, therefore the factors become (1.24) and (1.10) or <u>1.364</u> combined.

To illustrate how the dollarization of the Vought direct cost estimates was done, the following example of the LFRJ fuel tank with full bladder is used. This component is the same one used in the illustration on the materials estimating section. Starting with the materials estimate, it is seen that there are two parts to the materials cost:

<u>Vendor Non-Recurring</u>	<u>Total Recurring Cost</u>
\$9,900	\$1,330

These costs are representative of costs to the contractor, or direct costs; therefore, in order to obtain the cost to the government they must be adjusted.

Vendor non-recurring is treated as a direct material cost for tooling and must be burdened with the Materials Overhead and then by the combined G&A/Fee factor of (1.364).

$$\text{TCPF} = (\$9{,}900) \times (1.08) \times (1.364) = \$14{,}584$$

Both costs are recorded in Appendix 1 for reference. The \$9,900 is listed under column (5) "Tooling Materials non-recurring" and the \$14,584 is listed under column (6) "Purchased Tooling Cost". The purchased tooling cost is added to the other tooling costs where applicable.

The recurring materials cost is converted to selling price to the government by the following expression:

$$\text{TCPF} = \underbrace{(\text{Dir Mtl}) + (\text{Frt/Express}) + (\text{Mtl O/H}) + (\text{Mtl Handling})}_{\text{TDC}} \times (1.364)$$

$$\text{where (Frt/Express)} = (\text{Dir Mtl})\ \frac{1\%}{100}$$

$$(\text{Mtl O/H}) = (\text{Dir Mtl})\ \frac{8\%}{100}$$

$$(\text{Mtl Handling}) = (\text{Dir Mtl})\ (0.0039)\ (\$6.69)\ (1 + \frac{140\%}{100})$$

therefore,

$$\text{TCPF} = (\$1{,}330)\ [(1.0) + (0.01) + (.08) + (0.0039)\ (6.69)\ (2.40)] \times (1.364) = \$2{,}090$$

Again, both cost figures are reported in Appendix 1 for reference. The \$1,330 is listed as materials recurring, column (8), and the \$2,090 is listed as purchased materials recurring cost, column (9).

The dollarization of the tooling "labor" estimate for this component is obtained through the following relationship:

$$\text{TCPF} = \underbrace{(\text{Tooling Labor}) + (\text{Tlg Mtl}) + (\text{Tlg Dir Chgs})}_{\text{TDC}} \times (1.364)$$

Where, Tooling Labor = $\$9.89 \times (\text{manhours}) \times (1 + \frac{140\%}{100})$,

Tooling Mtls. = $1.214 \times (\text{manhours}) - 288.55$, (See Tooling Section)

Tooling Dir. Chgs. = $0.04 \times (\text{manhours})$, (See Tooling Section)

Therefore,

$$\text{TCPF} = [(9.89)(2150)(2.40) + (1.214)(2150) - 288.55 + (0.04)(2150)] \times (1.364) = \$72{,}891.$$

This calculated tooling labor cost is reported in column (4) of Appendix 1.

The total tooling cost is then the sum of the tooling labor cost and the vendor non-recurring which is \$72,891 plus \$14,584 or \$87,475. This is identified as the total tooling cost and shown in column (7). This is also the baseline tooling cost that is presented in the cost handbook for component C-4-1-1 for the 17-4 PH stainless steel and the Inconel-718.

The remaining element of cost for the fuel tank example is the manufacturing or production cost. In this case there is no sub-contracted work so the cost is basically all labor, which was estimated at 363.7 hours by detail part breakdown. The conversion to selling price follows the same basic equation:

$$\text{TCPF} = \underbrace{(\text{Shop Labor}) + (\text{Mfg Eng Support}) + \text{Qual Support})}_{\text{TDC}} \times (1.364)$$

Where, Shop Labor = $(\$7.04) \times (\text{Shop manhours}) \times (1 + \frac{140\%}{100})$

Mfg Eng Support = $(\$9.89) \times (\frac{12\%}{100})(\text{Shop manhours}) \times (1 + \frac{140\%}{100})$

Quality Support = $(\$7.73) \times (\frac{30\%}{100})(\text{Shop manhours}) \times (1 + \frac{140\%}{100})$

Combining all common terms, the equation becomes:

$$\text{TCPF} = (34.54) \times (\text{Shop Manhours}) = (34.54)(363.7) = \$12{,}562.$$

Summarizing, the total cost of the fuel tank assembly would then be the sum of the tooling, the material and the manufacturing which was just computed to be \$87,475, \$2,091 and \$12,562, respectively. The total cost of \$102,128 is then representative of the selling price on unit number one.

6. COST ADJUSTMENT FACTORS

The Cost Methodology was designed to allow a great amount of flexibility on the part of the cost analysts to look at a wide range of ramjet engine types, sizes and complexity and be able to compute costs for a range of production quantities and rates. Table 8 lists some of the primary choices that are available to the cost analyst. The range of choices was selected on the basis that these were the principal areas of consideration today.

TABLE 8

RANGE OF VARIABLES

Parameter	Range	Choices
Engine Type	4 Types	LFRJ, SFRJ, SDR, LDR
Configuration	3 Arrangements	Integral, Tandem, Podded
Size	6" - 18" Diam.	Variable within that range. Length also variable.
Quantity	1 - 5,000	Variable within that range.
Production Rate	Low-Moderate	1/month to 80/month.
Year of Production	Variable	Adjustable to any year from mid 1976.
Design Complexity	Simple-Moderate	Many choices available.
Materials	Several	3-structural materials 4-booster propellants 7-sustainer propellants
Manufacturing Processes	Several	Generally 2 or 3 choices for each component.
Labor Rate and Pricing Structure	Limited	Only broad adjustments possible.

Some of the choices are inherent in the selections of components that were made at the beginning of the program, but others are "scalable" by the use of cost adjustment factors that are provided in the methodology. The scalable parameters are (1) size, (2) production quantity, (3) production rate, and (4) year of production. A discussion of each of these factors is presented in the following sections.

a. Size Variations

Some of the factors that have an effect on cost of production of ramjet components are diameter, length, capture area (for inlets), surface area,

thickness, weight, volume, etc. These are general parameters that describe the physical size of the components or assemblies. The cost for each component in the cost handbook is presented for the baseline size (nominal 15-inch diameter engine); therefore an adjustment of that cost has to be made for application to other size engines--both larger and smaller. The approach taken in this program was to develop a size factor which could be used to multiply the baseline cost to obtain the cost for the larger or smaller component. Different size factors are employed for each of the three cost elements.

One of the tools available for determining cost sensitivity to size variations was a computer program that had been developed for the U.S. Army by Battelle for predicting the cost of rocket motors and nozzles, reference (13).

The basis for the Battelle costing methodology was the development of equations that were applicable to material, material forming, processirg (welding, machining, inspection, testing, etc.) and tooling requirements. An overall cost equation for the fabrication of a part from the raw material stage to the finished product stage can be expressed as:

$$C = C_T/Q + C_M + C_P + C_F$$

where,

C = Total Cost of Product Part

C_T = Cost of Tooling

Q = Quantity of Parts Produced

C_M = Cost of Material

C_P = Cost of Processing

C_F = Cost of Forming

The cost of material includes wastage and salvage factors. The cost of processing includes such factors as heat treating, inspection and testing. The cost of fabricating a piece of raw material into a specified shape or contour accounts for only those costs associated with sheet metal forming, forging, extruding, and machining. The tooling cost includes all costs associated with the fabrication of the particular part.

Because of the similarity of the rocket motor to several of the ramjet components (combustors, boosters, nozzles, fuel tanks and gas generators), the computer program could be employed to investigate the effect of varying many parameters in a rapid manner. An example of one of the sensitivity studies performed using the program is one dealing with a general combustor chamber configuration illustrated in Figure 34. Several parameters were varied over a number of values, and the total cost of the unit number one chamber was computed. Table 9 summarizes this particular study.

TABLE 9 COMBUSTOR SENSITIVITY STUDY COST SUMMARY

PARAMETER VARIATION		TOTAL UNIT COST
FWD HEAD CONTOUR = HEMISPHERICAL		61,372
BASELINE FWD HEAD CONTOUR = ELLIPTICAL		60,371
FWD HEAD CONTOUR = COMPLEX		60,371
BASELINE FWD HEAD CONTOUR = SIMPLE		60,371
DIAMETER = 5.0		31,146
DIAMETER = 18.0		65,697
DIAMETER = 25.0		86,595
BASELINE = 15.08		60,371
LENGTH = 25.0		59,732
LENGTH = 75.0		66,602
LENGTH = 150.0		67,036
BASELINE = 30.14		60,371
MATERIAL = INCONEL 718		65,883
MATERIAL = 4130 STEEL		79,568
MATERIAL = H-11 STEEL		79,663
BASELINE = 17-4 STAINLESS		60,371
CASE THICKNESS = .050		60,314
CASE THICKNESS = .150		61,476
CASE THICKNESS = .200		61,712
BASELINE = .090		60,371
QUANTITY = 10		8,484
QUANTITY = 50		3,166
QUANTITY = 250		1,800
QUANTITY = 500		1,590
QUANTITY = 1000		1,459
QUANTITY = 3000		1,314
QUANTITY = 6000		1,264
TOLERANCE = .001		60,480
TOLERANCE = .050		60,296
TOLERANCE = .100		60,296
BASELINE = .010		60,371
FWD SKIRT HOLE	.125	60,370
FWD SKIRT HOLE	.250	60,370
FWD SKIRT HOLE	.500	60,373
BASELINE = .3125		60,371
FWD SKIRT DRILL AXIS = PARALLEL TO ℄		57,784
BASELINE = PERPENDICULAR TO ℄		60,371
FWD SKIRT HOLES = 12		60,292
FWD SKIRT HOLES = 72		60,424
BASELINE = 48		60,371
FWD SKIRT MILLING WIDTH = .10		60,369
FWD SKIRT MILLING WIDTH = 2.00		60,373
BASELINE = 1.25		60,371
FWD SKIRT MILLING LENGTH = 5.00		60,369
FWD SKIRT MILLING LENGTH = 100.00		60,375
BASELINE = 46.34		60,371
FWD SKIRT MILLING THICKNESS = .025		60,370
FWD SKIRT MILLING THICKNESS = 1.00		60,418
BASELINE = .060		60,371

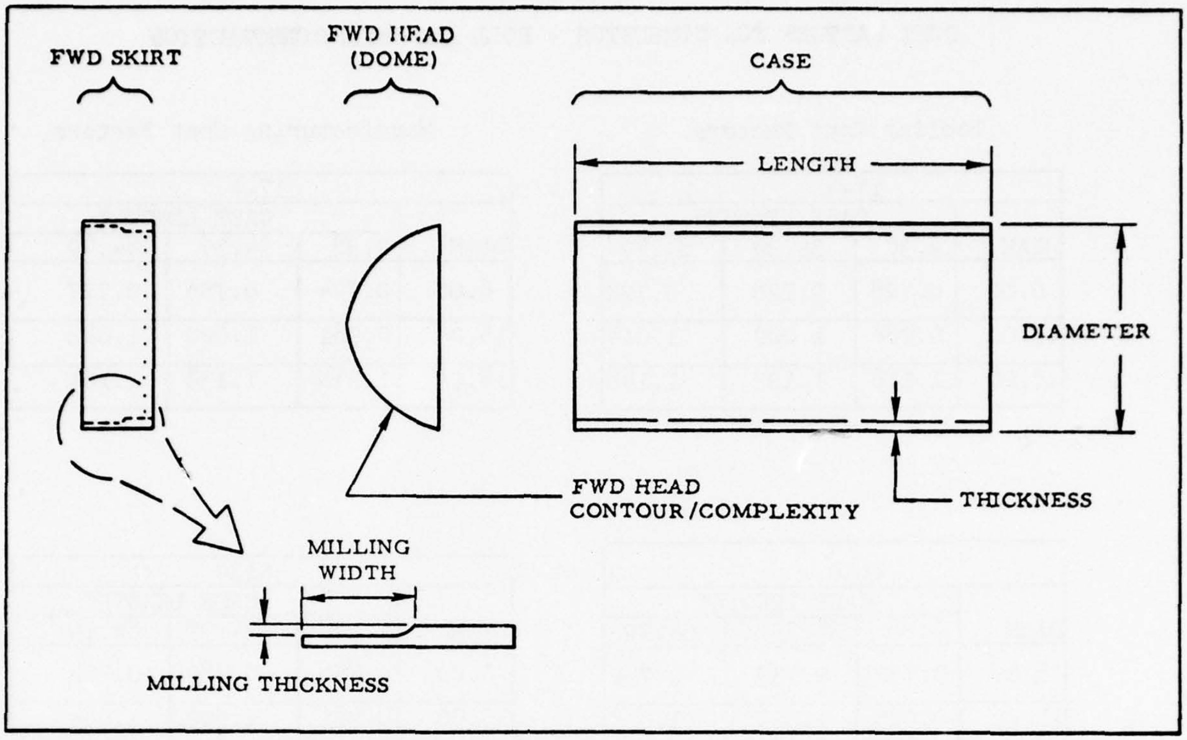


FIGURE 34 COMBUSTOR SENSITIVITY STUDY PARAMETER DEFINITION

The main interest in the usage of the program was to determine the effect of major size variations on cost. The main parameters of interest for the cylinderically shaped components was diameter and length. The computer program allowed the selection of a manufacturing process and structural material as well as determine the variation in cost for a number of those parameters. An example of the type of data generated for a roll and weld process is illustrated in Table 10.

The second method used to develop size factors is to make detailed cost estimates of the minimum and maximum sizes of components expected to be used with the minimum and maximum size engine configurations. Ratios of these costs to the baseline costs again produce size factors related to the baseline component cost.

A third method to develop size factors is to use engineering judgement to select size factors previously developed on other programs. These would be considered applicable to a component by similarity. A variation to this method is to assume that, for parts which vary only slightly with engine diameter and/or component length, the size factor is 1.0.

<u>Size Factor Coefficients</u> - Size factors are determined for the minimum, baseline, and maximum dimensions for each engine component. Factors either are dependent on one or two variables; i.e., inlet capture area, or engine diameter and/or component length. In order to obtain size factors for intermediate component sizes, the three or nine size factors representing the extreme sizes of the component are fitted to a parabolic or cubic curve. Curve fitting equations used are:

TABLE 10

COST FACTORS FOR COMBUSTOR - ROLL AND WELD CONSTRUCTION

Tooling Cost Factors

17-4			
	CASE LENGTH*		
DIAM	9.38	34.39	84.79
6.00	0.728	0.728	0.728
15.00	0.986	1.000	1.014
18.00	1.118	1.133	1.148

4130			
	CASE LENGTH*		
DIAM	9.38	34.39	84.79
6.00	0.732	0.732	0.732
15.00	0.985	1.000	1.015
18.00	1.118	1.134	1.150

INCONEL 718			
	CASE LENGTH*		
DIAM	9.38	34.39	84.79
6.00	0.728	0.728	0.728
15.00	0.986	1.000	1.014
18.00	1.118	1.133	1.148

Manufacturing Cost Factors

17-4			
	CASE LENGTH*		
DIAM	9.38	34.39	84.79
6.00	0.744	0.756	0.777
15.00	0.981	1.000	1.043
18.00	1.118	1.138	1.184

4130			
	CASE LENGTH*		
DIAM	9.38	34.39	84.79
6.00	0.758	0.769	0.794
15.00	0.981	1.000	1.044
18.00	1.119	1.139	1.185

INCONEL 718			
	CASE LENGTH*		
DIAM	9.38	34.39	84.79
6.00	0.651	0.661	0.681
15.00	0.984	1.000	1.036
18.00	1.178	1.195	1.234

Material Cost Factors

ANY MATERIAL			
	CASE LENGTH*		
DIAM	9.38	34.39	84.79
6.00	.056	.107	.212
15.00	.657	1.000	1.692
18.00	.833	1.346	2.281

* Case Length - Total Length Varies with Diameter.

$$SF = A01 + (A02)D + (A03)D^2 \tag{1}$$

or

$$SF = (A01)L + A02 + \left[(A11)L + (A12)\right] D + \left[(A21)L + A22\right] D^2 \tag{2}$$

When the coefficients of the D^2 term, A03 or $[(A21)L + A22]$, are zero, the curve fits are linear and parabolic, respectively. When both the D and D^2 coefficients in equations (1) and (2) become zero, the curve fits are linear.

Examples of some of the coefficients thus produced are shown in Tables 11 and 12. The cost handbook records a set of size factor coefficients for every cost element of every component in the handbook.

b. Production Quantity

The methodology provides a means of projecting the cost for ramjets for production quantities up to 5000. As in the case of the size adjustment of cost, a factor for each of the three cost elements of the components has been established that, when multiplied by the unit number one cost, will yield the cumulative average cost of the components for a given production size. This factor which is identified as the "quantity factor" is based on standard learning curve data for manufacturing labor costs. For materials costs, a quantity factor is based on reduction of costs through quantity purchases of materials, and for tooling costs it is based on equal proration of the total tooling cost over each part produced. An adjustment to the tooling quantity factor curve is made when the production rate exceeds 8 engines per month. It is believed that additional sets of tooling would be produced for higher production rates. Figure 35 illustrates how the tooling quantity factor curve is adjusted. An example of the quantity factor curves for the material cost and the manufacturing cost is shown in Figures 36 and 37 respectively.

A complete set of quantity factor curves similar to the ones illustrated here are presented in the cost handbook. The basic difference between the curves is the assumed slope of the learning curves. Each component data sheet in the cost handbook references the appropriate quantity factor curve to use when computing costs.

c. Production Rate

The assumption has been made on this program that within certain reasonable limits the ramjet cost is relatively unaffected by production rate. There is one area, however, that does have measurable impact on cost and that is in the tooling area. The previous assumption on production tooling was that one set of tools would easily handle up to 8 engines per month. Production rates in excess of 8 per month would be accomplished by the fabrication of extra sets of tools. In the quantity factor curves for tooling this is accomplished by the fabrication of extra sets of tools. In the quantity factor curves for tooling this is accomplished automatically by adjusting the curve as seen in Figure 35 at the bottom. This was done for the assumed 5000 engine production over a 5 year period (83.3 engines per month).

TABLE 11 SIZE FACTOR COEFFICIENTS - INLET ASSEMBLY

$$SF = A01 + A02\ (\text{CAPTURE AREA}) + A03\ (\text{CAPTURE AREA})^2$$

Material	Size Factor Element	Coefficients A01	A02	A03
17-4 PH	Tooling	0.583	0.0269	-0.000207
	Material	-0.057	0.0606	-0.000105
	Manufacturing	0.603	0.0252	-0.000174
4130	Tooling	0.564	0.0284	-0.000234
	Material	-0.057	0.0606	-0.000105
	Manufacturing	0.607	0.0248	-0.000167
Inconel 718	Tooling	0.696	0.0190	-0.000122
	Material	-0.057	0.0606	-0.000105
	Manufacturing	0.603	0.0252	-0.000174

TABLE 12 SIZE FACTOR COEFFICIENTS - COMBUSTOR CHAMBER ASSEMBLY

$$SF = (A01 \times L) + A02 + ((A11 \times L) + A12) \times D + ((A21 \times L) + A22) \times D^2$$

Matl	Cost Element	Coefficients A01	A02	A11	A12	A21	A22
17-4PH	Tool	-0.000490	0.675	0.0000979	0.000914	-0.00000270	0.00130
	Matl	-0.00338	-0.248	0.000753	0.0447	0.0000257	0.000471
	Mfg	-0.00000663	0.731	0.0000865	-0.00831	-0.00000209	0.00163
4130	Tool	-0.000530	0.689	0.000106	-0.00127	-0.00000294	0.00137
	Matl	-0.00338	-0.248	0.000753	0.0447	0.0000257	0.000471
	Mfg	0.0000397	0.768	0.0000862	-0.0131	-0.00000221	0.00178
Inc 718	Tool	-0.000490	0.675	0.000979	0.000914	-0.00000270	0.00130
	Matl	-0.00338	-0.248	0.000753	0.0447	0.00002578	0.000471
	Mfg	-0.0000928	0.635	0.0000582	-0.0119	-0.00000123	0.00231

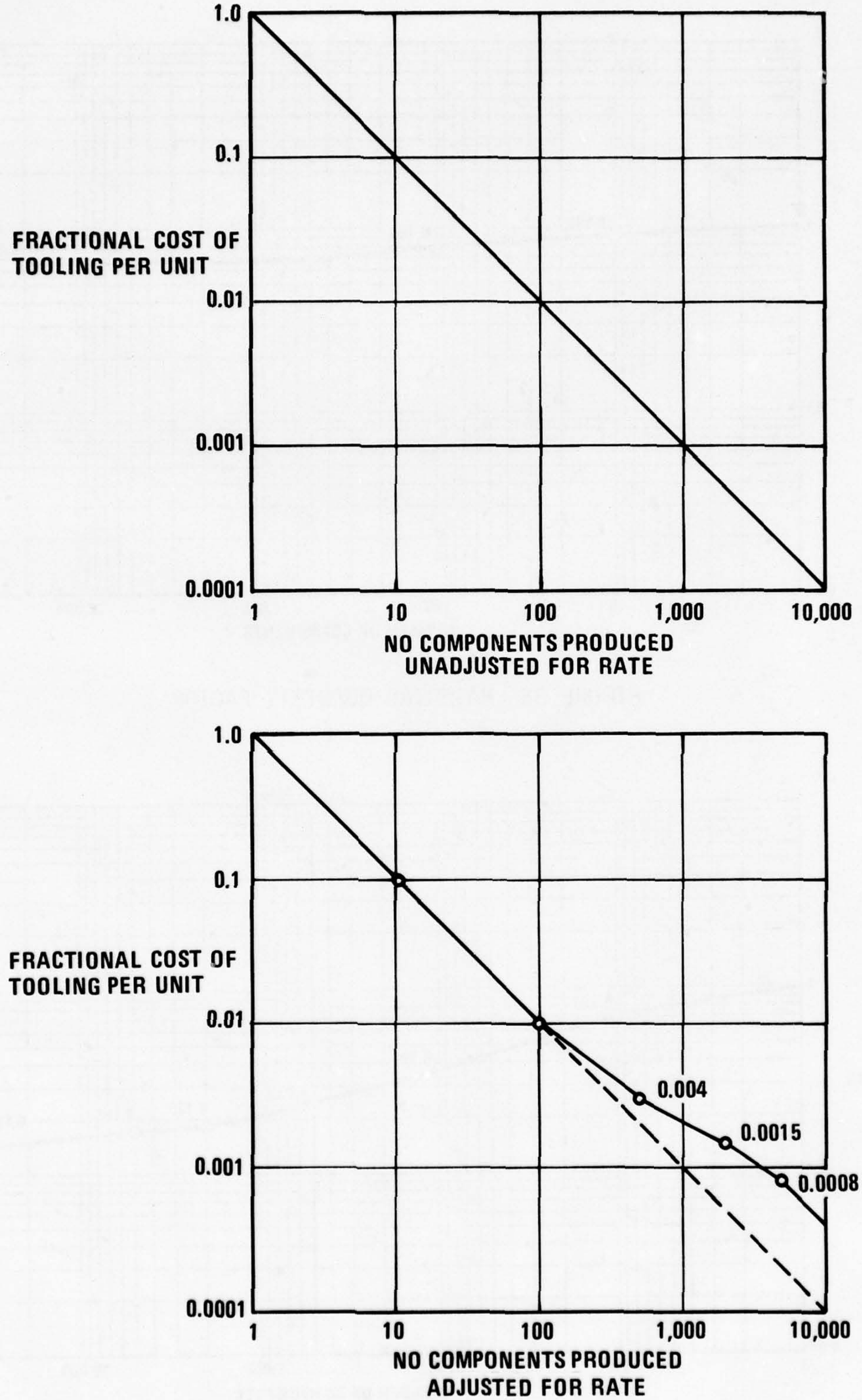


FIGURE 35 QUANTITY ADJUSTMENT CURVE - TOOLING

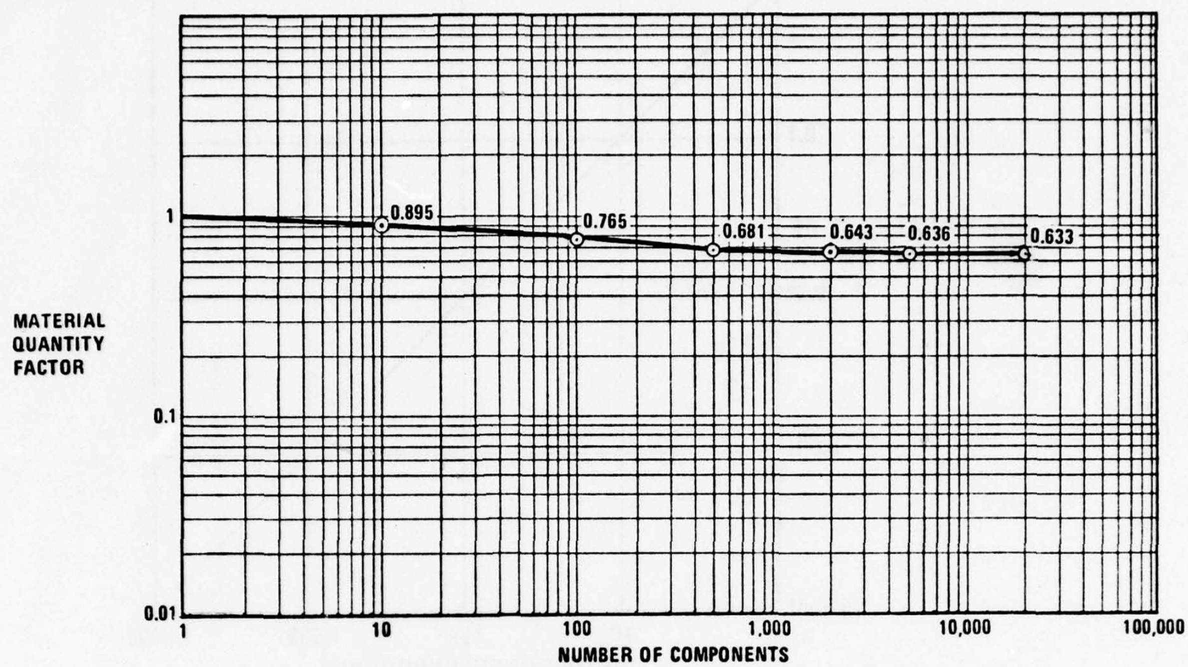


FIGURE 36 MATERIAL QUANTITY FACTOR

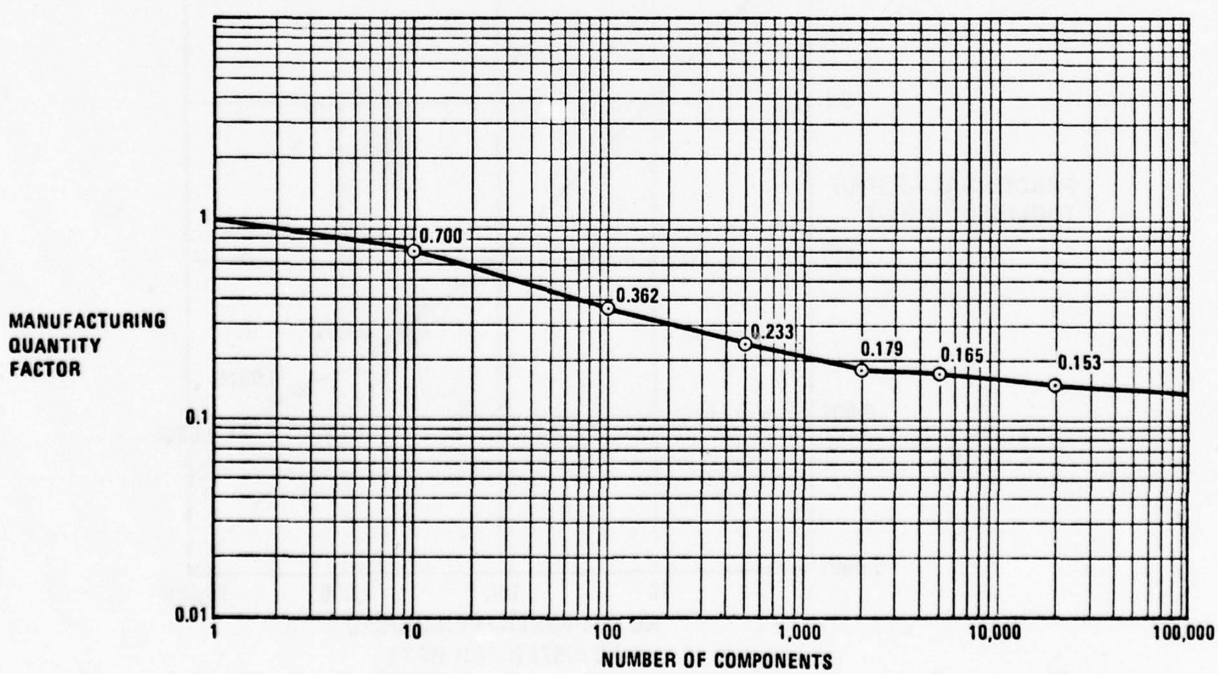


FIGURE 37 MANUFACTURING QUANTITY FACTOR

To cover the rate tooling effort for production programs of less than five years, the cost methodology includes a production rate factor for adjusting the tooling cost.

Because all components are not limited to production rates of 8 per month, many of the components in the cost handbook will have virtually no additional multiple tooling requirements until production rate exceeds 80 per month. An assessment has been made on every component and each one has been categorized into one of three categories which relate the number of components that can be produced in one month with one set of tools.

Category 1 ..... 80 parts/month

Category 2 ..... 30 parts/month

Category 3 ..... 8 parts/month

The total costs of tooling for production unit number one as shown in the cost handbook and in Appendix 1 (Column 7) include the costs of tool design, computer programming and many other items that would not appear if additional sets of tools were required, so the tooling cost is not simply a multiple of the stated tooling cost. The cost increase for multiple sets of tools was assumed to increase according to the following rates:

TABLE 13

COST MULTIPLIER FOR MULTIPLE TOOLING

No. Sets of Tools	1	2	3	5	7	10	20
Cost Multiplier	1.0	1.5	2.0	3.0	4.0	5.0	7.0

From this cost multiplier, the following tooling rate factors were constructed:

TABLE 14

TOOLING RATE FACTORS

COMPONENT CATEGORY	PRODUCTION RATE (COMPONENTS PER MONTH)					
	0-8	8-16	16-30	30-60	60-80	>80
1	1.0	1.0	1.0	1.0	1.0	1.5
2	1.0	1.0	1.0	1.5	2.0	3.0
3	1.0	1.5	2.5	4.0	5.0	6.0

This table is presented in the cost handbook and the individual component data sheets identify the category for each component.

d. Year of Production

The base period of production for this program has been assumed to be mid-1976. The labor rates, materials prices and general costing factors were based on data representative of mid-1976 rates. In order to project costs to other years, an adjustment of the base period cost is necessary.

The recommendation for this program is that of using an overall factor based on accepted cost indices. The Air Force recently published cost escalation data based on historical and forecasted data (Reference 8). Data from this report shows cost indices for three types of manufacturing; airframe, engine and avionics, and for different categories of costs like Engineering labor, manufacturing labor, materials costs, overhead, composite development costs and production costs. The recommendation made here is that the data on production costs representative of engine manufacturing be used.

A second source of cost escalation was found in the OSD (Comptroller) Escalation Indices dated August 1975. This is the one used by Victor (Reference (2)) to adjust costs. Both of these have been adjusted to 1976 and are shown in Table 15.

The suggestion on how to use these factors is to calculate the mid-year of production and use that date to adjust the baseline cost data. Thus a five-year production program starting in January 1978 would use an inflation factor of 1.365.

Jan 1978 + 5/2 = July 1980

e. Component Design Variations

One of the requirements of the methodology developed in this program is that the cost estimator's ramjet look something like the ramjet components that are contained in the cost handbook. The probability of finding a ramjet engine with every component exactly like those contained in the cost handbook is quite low; however, there are enough selections of component designs that one can come close to making a good comparison.

If the comparison between the candidate ramjet and the baseline components in the handbook is close, the recommendation is to use the cost data as it is presented in the handbook. If the differences are significant, there should be allowances made in the cost data to account for those differences. The data sheets for component costs have a block called "Other Factors" for special factors.

One way in which a person might gain some insight on costs for a component not listed in the cost handbook is to try to locate two components in the handbook that might bracket the costs. If one component is judged to be simpler than the one in question and a second component is judged to be more complex, the cost of the subject component should be in between.

In the final analysis, some engineering judgement will be required to adjust the costs to compensate for design variation. In many cases, the evaluator will have to consider not only manufacturing cost adjustments, but also tooling and materials adjustments.

TABLE 15

COST INFLATION FACTORS

COST INFLATION FACTORS		COST INFLATION FACTOR	
YEAR	INFLATION FACTOR	YEAR	INFLATION FACTOR
1976	1.000	1976	1.000
1977	1.092	1977	1.075
1978	1.178	1978	1.128
1979	1.271	1979	1.174
1980	1.365	1980	1.221
1981	1.453	1981	1.269
1982	1.547	1982	1.320
1983	1.650	1983	1.372
1984	1.737	1984	1.427
1985	1.808	1985	1.485
		1986	1.544
		1987	1.606
		1988	1.670
		1989	1.737
		1990	1.807
SOURCE: ASD Cost Escalation Report No. 110-C April 1976 (Production Data - Engine Mfg.)		SOURCE: OSD (COMPTROLLER) Escallation Indices August 1975	
RECOMMENDED FOR USE WITH VOUGHT COST METHODOLOGY			

f. Material Variations

The three main structural materials estimated in the program were 17-4PH stainless steel, 4130 high alloy steel, and a nickel base alloy, Inconel-718. These materials have been used by designers of high-performance aerodynamic missiles because of their high strength performance at high temperatures and their inherent resistance to environmental degradation (corrosion). Other materials could have been selected for the study program, but Vought's ALVRJ data base included specific cost data on many components using one or all of the three materials; therefore, cost data was generated for all three.

The methodology unfortunately does not allow the cost estimator completely free choice on the materials of construction for his ramjet. If his engine components are not constructed of one of these three alloys or a material similar to the alloys, the cost estimate can only be roughly approximated. Recognizing that this situation will exist, some general guidance is given in this section.

As seen in the previous section, the cost methodology provides a place for the cost estimator to employ factors in any area he choses. If his design is different, he may adjust the baseline cost by inserting a multiplier in the "Other Factors" column on the cost computation sheet and adjust any or all of the cost elements.

Materials variations can be handled the same way. It does require some engineering judgement on the part of the cost estimator if he expects to get reasonable results. If the material he wants to use in his ramjet is not one of the three listed in the handbook, he needs to think in terms of the key differences between his material and any one of the three listed and try to visualize what impact that has on cost. For example, if his material is easier to machine, drill, weld, he would expect the manufacturing cost to be somewhat less than the listed handbook costs. If it is more difficult to work, he should expect the manufacturing cost to be somewhat higher. The real question becomes that of how much higher or lower. That, of course, depends on how much machining or drilling or welding has to be done to that particular component and what the relative contribution to total manufacturing cost those operations have.

Referring back to the example in the manufacturing estimating section, the makeup of costs for manufacturing is split between many different kinds of operations. Table 16 shows the various shop elements that were involved in the fabrication of a 17-4 PH sheet metal inlet. A material other than 17-4 would be expected to have different estimates for each operation and thereby make the translation to manufacturing dollars rather difficult.

If the cost estimator knew exactly how much more difficult or easy his material was to work relative to one of the three materials, the details of the manufacturing estimates are not available to him in the cost handbook. Even if they were, his zeal for the task before him would no doubt diminish when he realized the amount of time he would have to spend with the resulting hundreds of detail cost computations that would be required on every component.

TABLE 16

MANHOUR SUMMARY - STANDARD HOURS
17-4 PH SHEET METAL INLET

Part Number	Description	Ship Qty	Machine Shop		Sheet Metal Shop		Bonding Shop		Weld Shop		Assembly	
			S/U	O/T	S/U	O/T	S/U	O/T	S/U	O/T	S/U	O/T
T180A110098-9	Flange	4			.47	.284						
T180A110098-10	Flange	4			.47	.300						
T180A110098-11	Fairing	4			.52	.824						
T180A110098-12	Forward Support	4			.47	.400			.17	.212		
T180A110098-13	Body	4			1.27	3.472			.55	2.120		
T180A110098-14	Floor	4			.70	3.312						
T180A110098-15	Splitter	4			.38	1.816						
T180A110098-16	Forward Ramp	4	4.40	5.292								
T180A110098-14-500	Floor Splitter Weld Assembly	4							.55	2.624		
T180A110098-17	Diverter	4			.13	.200						
T180A110098-18	Diverter	4			.13	.200						
T180A110098-19	Sub-Floor	4			.13	.200						
T180A110098-20	Foot	4			.38	.264						
T180A110098-21	Fairing Clip	8			.44	.448						
T180A110098-19-500	Sub-Floor, Diverter W/A	4							.25	7.092		
T180A110098-22	Rib	4			.13	.200						
T180A110098-23	Aft Flange	4	4.80	5.000								
T180A110098-24	Base Flange	4	5.38	9.244								
T180A110098-25	Boss (Igniter)	1	2.62	.628								
T180A110098-7-500 -8-500	Inlet Weldment Inlet Weldment	4							1.62	7.000		
T180A110098-7 -8	Inlet Weldment Inlet Weldment	4							.25	4.341		
T180A110098-4 -5 -6	Inlet RJ Igniter Inlet Quad Igniter Inlet Quad II & IV	4	25.22	35.085								
T180A110098-1 -2 -3	Inlet Assy-RJ Igniter Inlet Assy-Quad I Inlet Assy-Quad II & IV	4									-	1.412
TOTALS			42.42	55.249	5.62	11.920	0	0	3.39	23.389	0	1.412

He has two basic choices: He can accept the numbers of one of the three candidate structural materials or he can "modify" the cost of one of the materials by using some factor in the "Other Factor" column on the cost computation form. It is impossible to give guidance to the cost estimator without knowing full well that the advice is bound to be wrong for all situations but some generalizations may be helpful.

Relative to manufacturing costs, the approximation of cost variations between materials can sometimes be made by comparing the variation of standard hours for certain operations using different materials. Reference (16) showed some of this data. Table 17 is a partial summary of this data.

TABLE 17

STANDARD HOUR COMPARISONS

Operation	Dimensions	Aluminum	Titanium	Stainless Steel
Brake Forming	25-inches	.0056	.0154	.0056
End Mill	1 Pass 10-in. ½ diam. cutter	.0304	.1277	.1277
Drill	3/16-in. .125 gage	.0016	.0067	.0032
Turret Lathe	Face Chamfer	.0040 .0006	.0017 .0025	.0017 .0025
Counter Sink	3/16-inch	.0014	.0046	.0028
Square Shear	100 sq. in.	.0011	.0011	.0011

Vought made some rough estimates on a few components assumed to be constructed of titanium and found the manufacturing cost compared to the 17-4 PH cost numbers by factors ranging from 1.0 to 1.8 with most of them averaging around 1.3. Reference (2) shows a manufacturing cost factor of 1.4 for titanium compared to "steel." These bits of data then suggest that manufacturing costs for titanium would be expected to be slightly higher than say 17-4 stainless steel by 30-40%.

Tooling costs are very difficult to deal with here. Two of the three Vought selected materials have virtually the same tooling cost estimates. That is because the tooling philosophy adopted at the outset of the program could not distinguish significant differences in tooling requirements for the 17-4 PH stainless and the Inconel-718. The third material, however, was considered to be somewhat unique relative to tooling because of its requirement for a stress relieving heat treatment following any welding operation which required additional tool fixtures. The tooling costs for the 4130 steel are therefore typically higher than the other two materials. The only suggestion that might be made to the cost estimator is to again compare his material to

one of the three materials in the handbook. If significant differences in material processing are apparent, perhaps a slight adjustment would be in order for the tooling costs.

The third cost element, materials, is one that must be handled very carefully. There is a temptation to say if one material costs $5/lb. and another costs $10/lb., then the "material" costs for the second will be twice as much as the first. This is perhaps true if you are simply buying raw material, but this is not the case in this program. Most of the materials costs in this program reflect a complex combination of raw materials in various forms and purchased parts. Referring back to the Materials Estimating section, a summary of materials costs was shown in Table 3. It was seen that the materials cost is made up of a combination of raw materials (sheet, plate, rod, etc.) and purchased parts (bladder, vent screen, seals). Assuming that the cost estimator wanted to estimate the costs for a fuel tank made of structural material "X", he would have to go back to the detail estimating level which itemized the cost of every part as shown in the table. A simple ratio of raw material costs could be very misleading on a component like this one because in this case, the raw material costs are a small percentage of the total material cost. For example, in this case a five times increase in raw materials cost over the 17-4 PH would result in a total component cost increase of only about 60%.

To have any confidence in adjusting the cost estimates for different material, the estimator would have to have considerably more information than is available in the cost handbook. In some cases, he may be able to determine, based on the value of the baseline materials dollars in the cost handbook and the component sketch, that there are virtually no purchased parts or complicated materials estimate, and that the material costs are basically all raw materials. In this case, he may elect to use a raw material cost factor to adjust materials cost. For comparative purposes the approximate cost of the three baseline materials are presented in the following, Table 18.

TABLE 18

RAW MATERIAL COSTS

	17-4 PH	4130	IN-718
$/lb. (Sheet Stock)	2.25	.77	6.50
Ratio to 17-4 PH	1.0	.342	2.89

7. METHODOLOGY PROCEDURE

The previous sections have briefly described the types of ramjets that were considered in the program and gave some illustrations of typical components that would be candidates for the cost handbook. A description of how the baseline components were estimated followed by a discussion of how those baseline estimates were adjusted to compensate for size variations, etc., was also presented. This section will now describe the procedures that will be used by a ramjet cost estimator to arrive at the estimated production cost of his system.

It is assumed that the cost estimator has the following information before he can start the cost estimating.

(1) Description of the subject ramjet

- (a) Size - all key dimensions
- (b) Physical arrangement of components
- (c) Primary material(s) of construction
- (d) Type of propellants and fuels
- (e) Type of fuel management system - tank, pump, controls
- (f) General manufacturing processes employed (sheet metal, castings, weldments, etc.)

(2) Production time period (specific years and total time)

If he does not have some of the above data, he will have to make some assumptions and selections which will have impact on his costs. Those assumptions should be recorded on the data sheets so it will be documented for subsequent reference purposes.

a. Description of Data Sheets

There are two basic data sheets that are involved in the cost computation. The first data sheet is a cost summary data sheet for the complete ramjet assembly. There is one unique cost summary sheet for each of the eight ramjet types. Figure 38 illustrates the cost summary sheet for the Liquid Fuel Ramjet - Integral Rocket/Ramjet. Note that the data sheet has a section for each major subassembly.

LIQUID FUEL RAMJET – INTEGRAL ROCKET/RAMJET

AIR INDUCTION SYSTEM	(COMPONENT)	(SUBASSY)
A-1- INLET ASSEMBLY	( )	
A-2- INLET AFT FAIRING	( )	
A-3- INLET SIDE FAIRING	( )	
A-5- INLET OPTIONS	( )	
INLET OPTIONS	( )	
TOTAL AIR INDUCTION SYSTEM		( )
BOOSTER/COMBUSTOR		
B-1- COMBUSTOR CHAMBER	( )	
B-3- SUSTAINER NOZZLE	( )	
B-4-1 SUSTAINER IGNITER	( )	
B-5-1 BOOSTER IGNITER	( )	
B-6-2- BOOSTER PROPELLANT	( )	
B-7-1- BOOSTER NOZZLE	( )	
B-8- NOZZLE RETENTION	( )	
B- DOME OR CASE PORT COVER	( )	
B-13 BOOSTER/COMB OPTIONS	( )	
. BOOSTER/COMB OPTIONS	( )	
. BOOSTER/COMB OPTIONS	( )	
TOTAL BOOSTER/COMBUSTOR		( )

FUEL SYSTEM	(COMPONENT)	(SUBASSY)
C-1- SUSTAINER FUEL	( )	
C-4- FUEL TANK	( )	
C-6-1- FUEL DELIVERY	( )	
C-6-2- FUEL CONTROL	( )	
C-8- MANIFOLDS/INJECTORS	( )	
C-9- FMS COMPARTMENT	( )	
C-12- R.A.T. SCOOP	( )	
C-13- FUEL SYST OPTIONS	( )	
. FUEL SYST OPTIONS	( )	
TOTAL FUEL SYSTEM		( )
FINAL ASSEMBLY		
E-1 FINAL ASSY		( )
TOTAL RAMJET SYST COST		( )

ENGINE SIZE: ____________________

MATERIAL: ____________________

PRODUCTION QUANTITY: ____________________

PRODUCTION TERM: FROM __________ TO __________

OTHER CHARACTERISTICS: ____________________

FIGURE 38 COST SUMMARY SHEET

Components within those subassemblies are also listed in accordance with the WBS for the ramjet engine. Figure 39 illustrates the WBS for the LFRJ-IRR.

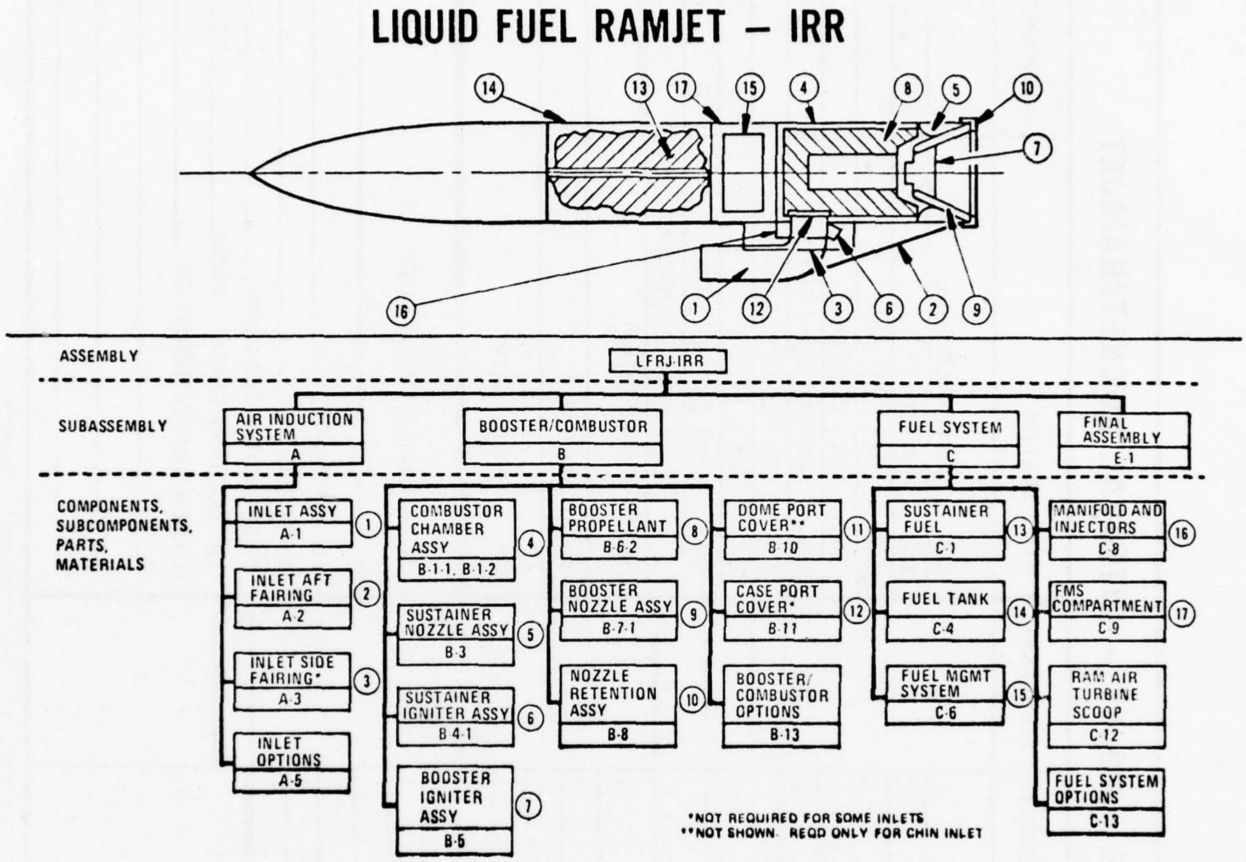


FIGURE 39 SYSTEM WBS

Note also that there is a designation of a component identification number, for example A-1- inlet assembly. This denotes that one of the inlet assemblies in the A-1 section of the cost handbook will be applicable to this engine type. (There are actually eight inlet assemblies under section A-1 but all of them do not necessarily apply to the LFRJ-IRR.) There is a blank in the second column next to the component title. This is for inserting the cost of that component after it has been computed.

The cost summary sheet also has a blank for the final assembly cost. The total ramjet system cost is computed by adding all of the individual cost elements on the data sheet. The data block in the lower right hand corner is primarily for reference purposes. It is for recording data such as engine size, materials, production quantity, dates of production assumed, etc.

The second data sheet (actually a series of similar data sheets) is the component cost computation sheet (see Figure 40). It is this data sheet that is used to compute the cost of the individual components that make up the ramjet assembly. There will be one data sheet for every component identified.

An illustration of a component cost computation sheet is given here. A brief description of each blank that must be filled by the user is given below (all other blanks are completed in the cost nandbook):

COMPONENT ID NO.:	NO. ENGINES REQD: TOTAL COMPONENTS REQD
COMPONENT DESCRIPTION:	ASSUMED PRODUCTION: YEARS; MID-YEAR
	ASSUMED INFLATION FACTOR: (SEE TABLE)
BASELINE COST COMPONENT SIZE: D =	COMPONENT PRODUCTION RATE: PER MONTH
SELECTED COMPONENT OPTION:	TOOLING RATE FACTOR: (SEE TABLE)
SELECTED COMPONENT SIZE: D =	SPECIAL FACTORS:
NO. COMPONENTS REQD PER ENGINE:	

BASELINE COST	OPTIONS			QUANTITY FACTOR CURVES	QUANTITY FACTOR	COMPUTED SIZE FACTOR	OTHER FACTORS
	17-4 STAINLESS STEEL	4130 STEEL	INCONEL 718				
TOOLING	$	$	$				
MATERIALS	$	$	$				
MANUFACTURING	$	$	$				

SIZE FACTOR COST ELEMENT	SIZE FACTOR COEFFICIENTS								
	17-4 STAINLESS STEEL			4130 STEEL			INCONEL 718		
	A01	A02	A03	A01	A02	A03	A01	A02	A03
TOOLING									
MATERIALS									
MANUFACTURING									

SIZE FACTOR EQUATION: $SF = A01 + (A02)D + (A03)D^2$ WHERE D =

TOOLING COST

(BASELINE COST) x (SIZE FACTOR) x (QUANTITY FACTOR) x (TOOLING RATE FACTOR) x (NO. PER ENGINE) x (OTHER FACTORS) = (TOTAL TOOL COST)

($) x ( ) x ( ) x ( ) x ( ) x ( ) = ($)

MATERIALS COST

(BASELINE COST) x (SIZE FACTOR) x (QUANTITY FACTOR) x (NO. PER ENGINE) x (OTHER FACTORS) = (TOTAL MTL COST)

($) x ( ) x ( ) x ( ) x ( ) = ($)

MANUFACTURING COST

(BASELINE COST) x (SIZE FACTOR) x (QUANTITY FACTOR) x (NO. PER ENGINE) x (OTHER FACTORS) = (TOTAL MFG COST)

($) x ( ) x ( ) x ( ) x ( ) = ($)

TOTAL COST PER ENGINE = ($)

TOTAL COST PER ENGINE ($)

INFLATION FACTOR x ( ) =

ADJUSTED COST PER ENGINE ($)

INSERT THIS VALUE IN COST SUMMARY TABLE

FIGURE 40 COMPONENT COST COMPUTATION SHEET

Many of the blanks in Figure 40 will already be completed in the cost handbook while others will be filled in by the cost estimator. A brief description of each blank is given below:

Component ID No. - This is the alpha-numeric designation that has been assigned to this particular component. Every component has a unique number.

Component Description - The name and brief description of the component.

Baseline Cost Component Size - Baseline costs for each component are given for a particular size component. This identifies the size of the baseline. In this case, D represents the capture area of the inlet in square inches or the diameter of the engine. (See note following the size factor equation near the center of the data sheet.)

Selected Component Option - On all component cost computation sheets there are more than one design option from which the cost estimator can select. In this example the options are the three different structural materials, 17-4 stainless steel, 4130 steel and Inconel-718. This blank is for recording which option the cost estimator will use in his cost computation.

Selected Component Size - This is for recording the size of the subject component to be costed. If the size is different than the baseline cost component size recorded, then a size factor computation will be required using the size factor equation given on the data sheet.

No. Components per Engine - In many cases there is more than one component employed in each engine, (for example 2 or 4 inlets per engine). This blank should record the total number of this particular component required per engine.

No. Engines Required - This is for recording the total production quantity of engines.

Total Components Required - This should be the product of the last two blanks. This number will be used in obtaining the quantity factor for each of the cost elements.

Assumed Production, Years, Mid Year - This is for the length of the production program and the mid point of that production period. This is for use in computing the Inflation Factor to be used in the cost computation.

Assumed Inflation Factor - This blank is for recording the factor as read from the Inflation Factor Table in the back of the cost handbook.

Component Production Rate - This should be the component production rate which is computed from the total components required and the length of the production period.

Tooling Rate Factor - This is for recording the tooling rate factor taken from the appropriate table in the back of the cost handbook. The referenced table automatically classifies the component into the proper category for reading the correct factor to be used.

Special Factors - This is a general blank for recording any information the cost estimator feels is pertinent to the estimate.

The next section of the data sheet contains the baseline cost data for the three cost elements (tooling materials and manufacturing) for each of the options that are listed. The costs are representative of unit number one production costs for the baseline size. Costs are selling cost to the government and reflect all contractor expenses plus fee.

Quantity Factor Curves - The unit one costs have to be multiplied by quantity factors which are taken from curves presented in the back of the cost handbook. This block identified the proper quantity factor curves to use for obtaining the correct factor to use for each of the cost elements.

Quantity Factor - This block is for recording the value of the quantity factor obtained using the referenced curve and the total components required.

Computed Size Factor - This block is for recording the size factors that are computed using the size factor equation, the coefficients listed on the data sheet and the subject component's size.

Other Factors - This block is a location for recording any optional factors the cost estimator wants to use. It might be a "complexity" factor or "materials" factor or any other adjustment he feels is warranted. If there are no adjustments, the factor of 1.0 should be employed for all three cost elements.

The next portion of the data sheet records the size factor coefficients that are recommended for use in the stated equation. Note that there are coefficients presented for each of the cost elements and each of the options. It is assumed that the cost estimator has access to a deck or pocket calculator for computing the size factor. Care should be given to this computation. Note that some of the coefficients will be negative. This particular data sheet shows a single variable with three coefficients. Other size factor equations will involve two variables and six coefficients.

The final segment of the cost computation sheet is where the actual cost computation is done. There is a blank to record the baseline cost of the selected option and blanks to record all of the factors that are computed and recorded elsewhere on the data sheet. The first line computes the tooling cost. Care should be taken to insure that the baseline cost and all the factors that are recorded here are the ones associated with tooling. Similarly the ones for materials and ones for manufacturing must be in the proper blank in order to compute the right cost. Note that since the baseline costs and quantity factors are based on the pro rata "per component" cost, each of the three cost elements must be multiplied by the number of components per engine to arrive at total cost per engine. A blank is provided for that in the computation.

After each of the cost elements are computed, they are recorded at the end of the lines and then they are summed to arrive at one total cost per engine in 1976 dollars. This is shown at the very bottom of the data sheet.

The block to the extreme right at the bottom is for applying the inflation factor multiplier since the computed costs have been based on mid-1976 rates. The final adjusted cost per engine at the bottom is the same figure that is also recorded on the cost summary sheet opposite the subject component.

b. Sample Calculation

A sample calculation is provided here to illustrate how the methodology is applied. The baseline assumption is summarized here:

Type of Ramjet:	LFRJ-IRR
Engine Diameter:	12"
Material of Construction:	4130 steel
Production Quantity:	2000 engine, 5 years starting 1977
<u>Air Induction System:</u>	2 inlets, 2-dimensional, sheet metal.
	o Capture area 19.8 in^2 per inlet
	o Side and Aft Fairings
<u>Booster/Combustor System:</u>	o Deep draw combustor chamber 32" length
	o Silica phenolic sustainer nozzle
	o Silica phenolic insert booster nozzle with metallic structure #2
	o Booster nozzle retention assembly
	o Case port covers (2)
	o Sustainer igniter, simple, externally located
	o Booster igniter, nozzle mounted
	o S/A with manual actuators
	o CTPB high smoke propellant
	o Continuous thermal insulation
<u>Fuel System</u>:	o Fuel: JP-5
	o Fuel tank - deep draw with standpipe and full bladder 43" length overall
	o FMS compartment 8" long
	o Turbopump and RAT scoop
	o Fuel control - pneumatic altitude control with hydraulic amplification
	o Wall mounted injectors in inlet pads
	o Submerged folding launch lug and tank sway brace FMS compartment submerged folding launch lug.

The following step-by-step procedure is described:

Step 1. Select from the eight choices of ramjet engine types the one that fits the subject engine to be costed. In this case it will be the LFRJ-IRR.

Step 2. Evaluate the WBS for that system to determine which sub-assemblies will require costing. Refer to the components listed in the WBS and the component numbers listed in the blocks. These will be the components that will normally make up the sub-assemblies.

Step 3. Take the cost summary sheet for that particular ramjet engine type. With the loose leaf feature of the cost handbook, it would be wise to duplicate this and other data sheets from the handbook so they can be used directly.

Step 4. Starting with the first component (in this case, the air induction system) select the component from the appropriate section of the handbook that best fits the design of the subject engine. Record on the data sheet the particular one selected. In the example, a sheet metal 2-D inlet was assumed. This is component A-1-2. Record on cost summary sheet.

AIR INDUCTION SYSTEM		(COMPONENT)
A-1-2	INLET ASSEMBLY	( )
A-2-	INLET AFT FAIRING	( )
A-3-	INLET SIDE FAIRING	( )

Step 5. Take the cost computation sheet for the component selected. It will be on the opposing page in the cost handbook. Record all of the appropriate data at the top of the page, e.g., size information, production information, etc.

COMPONENT COST COMPUTATION SHEET

COMPONENT ID NO.: A-1-2	NO. ENGINES REQD: 2000 TOTAL COMPONENTS REQD 4000
COMPONENT DESCRIPTION: 2-D AFT INLET ASSEMBLY - SHEET METAL CONSTRUCTION	ASSUMED PRODUCTION: 5 YEARS; MID-YEAR 1979
	ASSUMED INFLATION FACTOR: (SEE TABLE CI-1)
BASELINE COST COMPONENT SIZE: D = 18 IN²	COMPONENT PRODUCTION RATE: 66.7 PER MONTH
SELECTED COMPONENT OPTION: 4130 steel	TOOLING RATE FACTOR: (SEE TABLE TR-2)
SELECTED COMPONENT SIZE: D = 19.8 in²	SPECIAL FACTORS: None
NO. COMPONENTS REQD PER ENGINE: 2	

Step 6. Select from the options that are available, the one that best fits the subject engine. In this case, the options are the materials of construction, and in this problem the material is 4130 steel.

BASELINE COST PER INLET	OPTIONS			QUANTITY FACTOR CURVES	QUANTITY FACTOR	COMPUTED SIZE FACTOR	OTHER FACTORS
	17-4 STAINLESS STEEL	4130 STEEL	INCONEL 718				
TOOLING	$ 81,686.	$ 98,013.	$ 81,686.	T-1			
MATERIALS	$ 189.	$ 58.	$ 545.	MT-1			
MANUFACTURING	$ 6,283.	$ 6,628.	$ 17,622.	MF-1			

Step 7. Compute the size correction factors from the equation on the cost computation sheet, the coefficient and the size data. Record in the appropriate column. Note that on this component there are three size factors -- one for tooling, materials and manufacturing. Use the coefficients for the option selected.

SIZE FACTOR COST ELEMENT	SIZE FACTOR COEFFICIENTS								
	17-4 STAINLESS STEEL			4130 STEEL			INCONEL 718		
	A01	A02	A03	A01	A02	A03	A01	A02	A03
TOOLING	.58310	.026903	-.00020788	.56390	.028450	-.00023456	.69633	.019074	-.00012243
MATERIALS	-.056859	.060601	-.00010479	-.056859	.060601	-.00010479	-.056859	.060601	-.00010479
MANUFACTURING	.61563	.024434	-.00017115	.60562	.02530	-.00018839	.61054	.024735	-.00017214
SIZE FACTOR EQUATION: $SF = A01 + (A02)D + (A03)D^2$ WHERE D = CAPTURE AREA PER INLET									

The equation for the tooling size factor is

$$SF = .56390 + .02845\ (19.8) - 0.00023456\ (19.8)^2 = 1.0353$$

Record on the cost computation sheet

QUANTITY FACTOR CURVES	QUANTITY FACTOR	COMPUTED SIZE FACTOR	OTHER FACTORS
T-1		1.0353	
MT-1			
MF-1			

Repeat for the other size factors and record.

Step 8. Determine the quantity factors by referring to the quantity factor curves listed on the data sheet. (In this case T-1, MT-1, MF-1 are referenced.) these curves, in the back of the cost handbook will present the Quantity Factor versus Production Quantity. Read the appropriate curve and record the factors on the cost computation sheet.

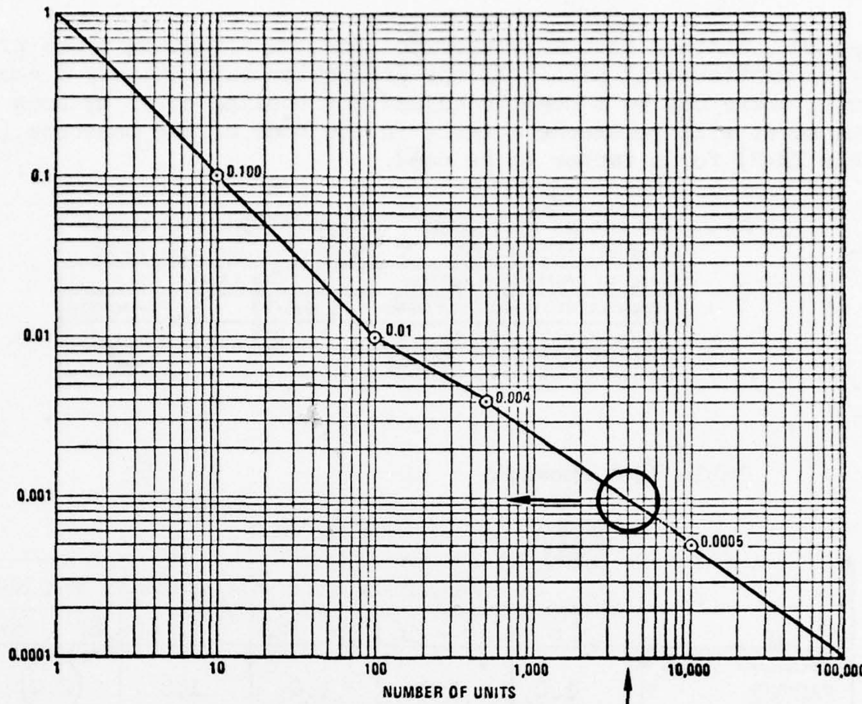


FIGURE T-1. TOOLING QUANTITY FACTOR

Read from the curve for total number of components to be produced (4000). The quantity factor for tooling is 0.001. Record this in the quantity factor blank. Repeat for the other two quantity factors.

QUANTITY FACTOR CURVES	QUANTITY FACTOR	COMPUTED SIZE FACTOR	OTHER FACTORS
T-1	0.001	1.0353	
MT-1		1.1020	
MF-1		1.0327	

Step 9. There is a provision in the methodology to allow the cost estimator to make adjustments in the costs for whatever reason he may wish. For example, if his component is not quite the same as one in the handbook he should pick one that is similar to his and use a complexity factor. If he feels that his component is more complex by 50%, he would insert a 1.5 factor into the other factors column. If he felt his would be 80% as costly he would use 0.80 in the other factor column. Again he can vary any of the three cost elements if he desires. In this example there is no need for adjustment we will insert a 1.0 which is used to represent "no change".

QUANTITY FACTOR CURVES	QUANTITY FACTOR	COMPUTED SIZE FACTOR	OTHER FACTORS
T-1	0.001	1.0353	1.0
MT-1	0.639	1.1020	1.0
MF-1	0.170	1.0327	1.0

Step 10. Another factor is provided for the situation where production rate may be particularly high. If the production rate exceeds 8 components per month, there may be a need to adjust the tooling costs by some factor. The data sheet will reference a table in the back of the handbook (in this case Table TR-2) for a factor to be used.

NO. ENGINES REQD: 2000	TOTAL COMPONENTS REQD 4000
ASSUMED PRODUCTION: 5 YEARS;	MID-YEAR 1979
ASSUMED INFLATION FACTOR:	(SEE TABLE CI-1)
COMPONENT PRODUCTION RATE: 66.7	PER MONTH
TOOLING RATE FACTOR:	(SEE TABLE TR-2)
SPECIAL FACTORS: None	

Table TR-2 shows:

TABLE TR-2

	PRODUCTION RATE (COMPONENTS PER MONTH)					
	≪8	8 - 16	16 - 30	30 - 60	60 - 80	>80
TOOLING RATE FACTOR	1.0	1.0	1.0	1.5	2.0	3.0

Insert the factor 2.0 in the blank

NO. ENGINES REQD: 2000	TOTAL COMPONENTS REQD 4000
ASSUMED PRODUCTION: 5 YEARS;	MID-YEAR 1979
ASSUMED INFLATION FACTOR:	(SEE TABLE CI-1)
COMPONENT PRODUCTION RATE: 66.7	PER MONTH
TOOLING RATE FACTOR: 2.0	(SEE TABLE TR-2)
SPECIAL FACTORS: None	

Step 11. The cost estimator is now able to compute the total cost of the component. At the bottom of the cost computation sheet are blanks which use the data on the sheet to compute the costs. In this example there are three cost elements that are computed and added together to arrive at the total cost of that component. For example, the total tooling cost would be computed by multiplying the baseline tooling cost from the selected option by the tooling size factor, quantity factor, number of components per engine, tooling rate factor and other factors (if appropriate).

TOOLING COST (BASELINE COST) × (SIZE FACTOR) × (QUANTITY FACTOR) × (TOOLING RATE FACTOR) × (NO. PER ENGINE) × (OTHER FACTORS) = (TOTAL TOOL COST) ($ 98,013) × (1.0353) × (0.001) × (2.0) × (2) × (1.0) = ($ 405.89)	TOTAL COST PER ENGINE ($)
MATERIALS COST (BASELINE COST) × (SIZE FACTOR) × (QUANTITY FACTOR) × (NO. PER ENGINE) × (OTHER FACTORS) = (TOTAL MTL COST) ($) × ( ) × ( ) × ( ) × ( ) = ($)	INFLATION FACTOR × ( ) =
MANUFACTURING COST (BASELINE COST) × (SIZE FACTOR) × (QUANTITY FACTOR) × (NO. PER ENGINE) × (OTHER FACTORS) = (TOTAL MFG COST) ($) × ( ) × ( ) × ( ) × ( ) = ($)	ADJUSTED COST PER ENGINE ($) INSERT THIS VALUE IN COST SUMMARY TABLE
TOTAL COST PER ENGINE = ($)	

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PRODUCTION/COST ANALYSIS OF RAMJET ENGINES. VOLUME I.(U)

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2 OF 2

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The same thing would be done for the materials cost and manufacturing costs. The three elements would then be added to become the total cost per engine.

TOOLING COST						
(BASELINE COST) ×	(SIZE FACTOR) ×	(QUANTITY FACTOR) ×	TOOLING (RATE FACTOR) ×	(NO. PER ENGINE) ×	(OTHER FACTORS) =	(TOTAL TOOL COST)
($ 98,013) ×	(1.0353) ×	(0.001) ×	(2.0) ×	(2) ×	(1.0) =	($ 405.89)
MATERIALS COST						
(BASELINE COST) ×	(SIZE FACTOR) ×	(QUANTITY FACTOR) ×		(NO. PER ENGINE) ×	(OTHER FACTORS) =	(TOTAL MTL COST)
($ 58) ×	(1.102) ×	(0.639) ×		(2) ×	(1.0) =	($ 81.68)
MANUFACTURING COST						
(BASELINE COST) ×	(SIZE FACTOR) ×	(QUANTITY FACTOR) ×		(NO. PER ENGINE) ×	(OTHER FACTORS) =	(TOTAL MFG COST)
($ 6,628) ×	(1.0327) ×	(0.170) ×		(2) ×	(1.0) =	($ 2,327.21)
					TOTAL COST PER ENGINE =	($ 2,814.78)

TOTAL COST PER ENGINE
($ 2,815)
INFLATION FACTOR
× ( ) =
ADJUSTED COST PER ENGINE
($)
INSERT THIS VALUE IN COST SUMMARY TABLE

Step 12. The only remaining calculation on the computation sheet deals with inflation factor. All of the cost data is representative of mid-1976 costs; therefore, if the production time-frame is different an adjustment must be made according to the inflation factors listed in the table in the back of the cost handbook.

TABLE CI-1

COST INFLATION FACTORS

YEAR	INFLATION FACTOR
1976	1.000
1977	1.092
1978	1.178
→ 1979	1.271
1980	1.365

In the example problem we assumed a five year program beginning in 1977 which would put the mid point ofthe program at mid-1979 (January 1977 + 2 years = July 1979) which gives a factor of 1.271. This factor is used to adjust the 1976 cost to the production mid year.

TOTAL COST PER ENGINE
($ 2,815)
INFLATION FACTOR
× (1.271) =
ADJUSTED COST PER ENGINE
($ 3,578)
INSERT THIS VALUE IN COST SUMMARY TABLE

This adjusted cost is the component cost that should be inserted on the cost summary sheet.

AIR INDUCTION SYSTEM	(COMPONENT)	(SUBASSY)
A-1- INLET ASSEMBLY	(3,578)	
A-2- INLET AFT FAIRING	( )	
A-3- INLET SIDE FAIRING	( )	
A-5- INLET OPTIONS	( )	
INLET OPTIONS	( )	
TOTAL AIR INDUCTION SYSTEM		( )

Step 13. Repeat steps 4 through 12 for the second component on the cost summary sheet. Continue until all of the component costs have been calculated and recorded on the cost summary sheet.

All of the component cost computation sheets are similar to the one used for this example, but with some small variations. The greatest difference is that all components do not have three cost elements to compute. Instead of having tooling, materials and manufacturing cost elements, the component cost is "total cost" as seen in the case of the sustainer igniter (component B-4-1-1).

COMPONENT ID NO.: B-4-1-1	NO. ENGINES REQD: TOTAL COMPONENTS REQD
COMPONENT DESCRIPTION: SUSTAINER IGNITER - EXTERNAL - LFRJ	ASSUMED PRODUCTION: YEARS: MID-YEAR
	ASSUMED INFLATION FACTOR: (SEE TABLE CI-1)
BASELINE COST COMPONENT SIZE: D = 15"	COMPONENT PRODUCTION RATE: PER MONTH
SELECTED COMPONENT OPTION:	TOOLING RATE FACTOR: (SEE TABLE TR-1)
SELECTED COMPONENT SIZE: D =	SPECIAL FACTORS:
NO. COMPONENTS REQD PER ENGINE:	

BASELINE COST	OPTIONS				QUANTITY FACTOR CURVES	QUANTITY FACTOR	COMPUTED SIZE FACTOR	OTHER FACTORS
	DUAL INITIATORS	DUAL BRIDGEWIRES	SIMPLE NOZZLE					
TOTAL COST	$ 9,127	$ 8,116	$ 7,483	$	TC-1			

The tables and figures to use are also slightly different, but the methodology for computing cost is identical.

As the cost estimator continues down the list, he records the cost of each component on the cost summary sheet.

Step 14. The only remaining cost computation is that of the final assembly. There is a schematic flow chart of the final assembly operations and a cost computation sheet for each of the eight ramjet engine types. Select the appropriate cost computation sheet and compute costs exactly as they were done for the components. Record the assembly cost on the cost summary sheet.

Step 15. The major sub-assembly costs can now be determined by adding all of the individual component costs under each section. The total engine costs are then computed by adding all of the sub-assembly costs and the final assembly cost. A completed cost summary sheet is attached.

TABLE I-1 COST SUMMARY SHEET

LIQUID FUEL RAMJET – INTEGRAL ROCKET/RAMJET

AIR INDUCTION SYSTEM	(COMPONENT)	(SUBASSY)
A-1-2 INLET ASSEMBLY	(3,578)	
A-2-1 INLET AFT FAIRING	(1,051)	
A-3-1 INLET SIDE FAIRING	(784)	
A-5- INLET OPTIONS	(–)	
INLET OPTIONS	(–)	
TOTAL AIR INDUCTION SYSTEM		(5,413)
BOOSTER/COMBUSTOR		
B-1-1-2 COMBUSTOR CHAMBER	(2,377)	
B-3-1 SUSTAINER NOZZLE	(1,487)	
B-4-1-1 SUSTAINER IGNITER	(895)	
B-5-2 BOOSTER IGNITER	(994)	
B-6-2-2 BOOSTER PROPELLANT	(3,031)	
B-7-1-3 BOOSTER NOZZLE	(1,844)	
B-8-1 NOZZLE RETENTION	(150)	
B-11 DOME OR CASE PORT COVER	(111)	
B-13-5 BOOSTER/COMB OPTIONS	(5,970)	
-8 BOOSTER/COMB OPTIONS	(716)	
- BOOSTER/COMB OPTIONS	(–)	
TOTAL BOOSTER/COMBUSTOR		(17,575)

FUEL SYSTEM	(COMPONENT)	(SUBASSY)
C-1-1 SUSTAINER FUEL	(86)	
C-4-1-2 FUEL TANK	(3,337)	
C-6-1-1 FUEL DELIVERY	(3,360)	
C-6-2- FUEL CONTROL	(902)	
C-8-1 MANIFOLDS/INJECTORS	(204)	
C-9- FMS COMPARTMENT	(1,238)	
C-12- R.A.T. SCOOP	(765)	
C-13-3 FUEL SYST OPTIONS	(1,135)	
-4 FUEL SYST OPTIONS	(346)	
TOTAL FUEL SYSTEM		(11,373)
FINAL ASSEMBLY		
E-1 FINAL ASSY		(3,003)
TOTAL RAMJET SYST COST		(37,364)

ENGINE SIZE: 12" DIAM

MATERIAL: 4130 STEEL

PRODUCTION QUANTITY: 2000

PRODUCTION TERM: FROM JAN 1977 TO JAN 1982

OTHER CHARACTERISTICS:

8. VERIFICATION OF METHODOLOGY

Since there is little production cost data directly applicable to ramjet engines, the verification of the accuracy of the Vought methodology has been attempted by making comparison with a number of other cost estimates on ramjets or ramjet sub-assemblies. A brief discussion of some of these comparisons follows:

Solid Rocket Motor: The most meaningful accuracy test is one which permits comparison of costs predicted by the Vought methodology with actual historical cost data. The solid rocket motor represents perhaps the only sub-assembly included in the Vought methodology for which such a historical cost data base exists. Booz-Allen completed a study in 1975 in which a Cost Estimating Relationship (CER) was developed from historical cost data for 27 different solid motors. The CER selected is based upon total motor weight, propellant mass fraction, and specific impulse, and fits the data with a standard estimate error of 46%. In order to compare the Vought methodology and Booz-Allen CER, costs were generated using both approaches for three different solid motors. One of the solid motors has a 15-inch diameter and 35-inch cylindrical length. The second and third motors are 6 inches in diameter and have cylindrical lengths of 35 and 75 inches. The Vought methodology assumptions and results are shown in Table 19. The assumptions and results for the Booz-Allen CER are shown in Table 20.

The Vought methodology assumptions for case metallics and propellant types are consistent with the motors evaluated by Booz-Allen. The propellant weights used as input to the Booz-Allen approach are those supplied with the information furnished by Rocketdyne. The mass fractions shown are typical of solid motors. However, an examination of the Booz-Allen CER disclosed that variation in mass fraction from 0.6 to 0.85 at constant propellant weight results in cost changes of only 5 percent. The sea level specific impulse assumptions shown are achievable with the propellant selected. However, it should be noted that the Booz-Allen CER is heavily specific impulse weighted and a reduction in specific impulse of 10 sec results in a cost decrease of approximately 8 percent.

A comparison of the cost estimates can be seen in Table 21. The table shows the ratio of the costs for each of the three rocket motors at the three different quantities. The only real significant differences in estimates occurs for the unit number one costs where it is seen that Vought's methodology predicts significantly higher costs. This is probably because the entire "production tooling" cost is contained in that estimate.

TABLE 19

COST SUMMARY FOR SIMPLE BOOSTERS USING VOUGHT DEVELOPED METHODOLOGY

Component	Cost @ Unit 1 ($)	Avg Cost for 1500 Units	Avg Cost for 5000 Units
. 4130 Case and Nozzle Metallics . HTPB High Smoke Propellant . 15" Diameter Case			. 35" Cylindrical Motor Length . 1976 Dollars
Case	130,774	1,777	1,477
Nozzle	62,100	1,664	1,436
Igniter	2,936	934	669
Propellant	55,770	4,877	3,559
Total	251,580	9,252	7,141
. 4130 Case and Nozzle Metallics . HTPB High Smoke Propellant . 6" Diameter Case			. 35" Cylindrical Motor Length . 1976 Dollars
Case	75,120	1,091	901
Nozzle	23,119	492	415
Igniter	2,230	354	254
Propellant	33,406	2,259	1,604
Total	133,875	4,196	3,174
. 4130 Case and Nozzle Metallics . HTPB High Smoke Propellant . 6" Diameter Case			. 75" Cylindrical Motor Length . 1976 Dollars
Case	83,263	1,171	970
Nozzle	23,119	492	415
Igniter	2,230	354	254
Propellant	43,267	2,582	1,851
Total	151,879	4,599	3,490

TABLE 20

SOLID MOTOR COSTS BASED ON BOOZ-ALLEN CER

Element	Solid Motor Description		
	15" Diameter 25" Length	6" Diameter 36" Length	6" Diameter 75" Length
Propellant Wt., lbs	362	53	108
Mass Fraction	0.70	0.70	0.70
Specific Impulse, sec. (at sea level)	250	250	250
Unit 1 Base Cost (1973 Dollars)	17,110	4,208	6,992
Unit 1 Cost Adj. for Fwd and Aft Attachments, Fin Actuator Bosses, and Temperature Capability	23,400	5,755	9,562
Adjusted Unit 1 Cost in 1976 Dollars (per Ref. 5, Engine Proc.)	32,339	7,953	13,215
Adjusted Avg. Unit Cost @ 1,500 Units	10,284	2,529	4,202
Adjusted Avg. Unit Cost @ 5,000 Units	8,246	2,028	3,370

TABLE 21

COMPARISON BETWEEN BOOZ-ALLEN AND VOUGHT COST ESTIMATE

Solid Motor	Unit No. 1 Cost Ratio (Vought/B-A)	Unit 1500 Cost Ratio (Vought/B-A)	Unit 5000 Cost Ratio (Vought/B-A)
15" Diam 35" Length	7.77	0.899	0.866
6" Diam 35" Length	16.83	1.66	1.56
6" Diam 75" Length	11.49	2.27	1.03

Inlet Assembly: The 2-D sheet metal inlet costs generated by Vought for the cost methodology have been compared with cost estimates made by Boeing for a 2-D sheet metal inlet designed for the Modern Ramjet Engine (MRE). In order that the two inlet design concepts have similar complexity, the Vought inlet concept must include the basic inlet, two side fairings, an aerodynamic grid, and an inlet extension (welded to combustor and normally considered a part of the combustor assembly). The Vought inlet assembly thus defined has 32 detail parts including the cast inlet extension. The Boeing inlet has approximately 39 detail parts. Since the Vought inlet extension is a casting which takes the place of several detail parts, the two inlet assemblies are considered to be comparable with regard to part number complexity.

Cost estimates generated using the Vought methodology are presented in Tables 22 and 23 for inlets constructed from 4130 and Inconel 718. These data are applicable to an inlet capture area of approximately 18 square inches and are based on a mid-1976 economy. In order to be able to compare these data with the Boeing data, adjustments are required for capture area increase to 40 square inches and de-escalation to a mid-1974 economy. A capture area of 40 square inches was calculated for the MRE inlet without the inlet precompression shroud. The shroud does not contribute significantly to the Boeing inlet cost and would result in an excessive correction if accounted for in the Vought size factor. The correction factors and adjusted data are shown in Table 24.

A comparison of the adjusted Vought data and the Boeing data shown in Table 24 shows that the Boeing data is lower by 22 percent for the 4130 material at 2,000 units. Deleting the perforation bleed holes and seal ring groove on the Vought inlet (these items are not included in the Boeing design) reduces the difference to 15.4 percent. Comparable cost data for the manufacturing element of the Inconel 718 inlets shows that the Boeing estimate is 46 percent lower than the Vought estimate. The source of this rather large difference in the Inconel estimate may be due to a proportionately greater amount of machining required for the Vought inlet design.

TABLE 22

COST SUMMARY FOR 2-D 4130 STEEL INLET ASSEMBLY USING VOUGHT DEVELOPED METHODOLOGY

- 18 in^2 Capture Area
- 1976 Dollars
- Inlet Extension, Aero Grid, and Side Fairings included

Component	Element	Cost @ Unit 1	Av. Cost for 20 Units	Avg. Cost for 2,000 Units
2-D Sheet Metal Inlet	Mfg.	6,628	3,911	1,186
	Matls.	58	50	37
	Tooling	98,013	4,901	157
	Total	104,699	8,862	1,380
2-D Inlet Side Fairings	Mfg.	1,382	815	247
	Matls.	34	29	22
	Tooling	22,546	1,127	34
	Total	23,962	1,971	303
Inlet Extension (Costed as part of combustor)	Mfg.	509	300	91
	Matls.	122	104	78
	Tooling	21,047	1,052	32
	Total	21,678	1,456	201
Aerodynamic Grid	Mfg.	294	173	53
	Matls.	104	89	67
	Tooling	13,569	678	20
	Total	13,967	940	140
Total Assy	Mfg.	8,813	5,199	1,577
	Matls.	318	272	204
	Tooling	155,175	7,758	243
	Total	164,306	13,229	2,024

TABLE 23

COST SUMMARY FOR 2-D INCONEL-718 INLET ASSEMBLY USING VOUGHT DEVELOPED METHODOLOGY

. 18 in^2 Capture Area			. Inlet Extension, Aero Grid, and Side Fairings included	
Component	Element	Cost @ Unit 1	Avg. Cost for 20 Units	Avg. Cost for 2,000 Units
2-D Sheets Metal Inlet	Mfg.	17,622	10,397	3,154
	Matls.	545	466	350
	Tooling	81,685	4,084	123
	Total	99,852	14,947	3,627
2-D Inlet Side Fairings	Mfg.	2,573	1,518	461
	Matls.	318	272	204
	Tooling	14,843	742	22
	Total	17,734	2,532	687
Inlet Extension (Costed as part of combustor)	Mfg.	2,036	1,201	364
	Matls.	620	530	399
	Tooling	21,047	1,052	32
	Total	23,703	2,783	795
Aerodynamic Grid	Mfg.	515	304	92
	Matls.	129	110	83
	Tooling	13,569	678	20
	Total	14,213	1,092	195
Total Assy.	Mfg.	22,746	13,420	4,071
	Matls.	1,612	1,378	1,036
	Tooling	131,144	6,556	197
	Total	155,502	21,354	5,304

TABLE 24

2-D SHEET METAL INLET COST COMPARISON

Vought Size Factors for 40 in^2 Capture Area		
Element	4130	Inconel 718
Mfg.	1.3162	1.3250
Matls.	2.1995	2.1995
Tooling	1.3266	1.2634

Inflation Factor for 1974 to 1976 Dollars (Reference 5)
Escalation index for Engine Proc, 1974 to 1976 dollars is 1.226.

Comparison of Boeing Costs with Vought Costs Adjusted to 40 in Ac and 1974 $						
	Vought Cum Avg. Costs			Boeing Cum Avg. Costs		
Element	4130 @ 20 Units	4130 @ 2,000 Units	Inconel 718 @ 2,000 Units	4130 @ 20 Units	4130 @ 2,000 Units	Inconel 718 @ 2,000 Units
Mfg.	5,582	1,693*	4,400**	4,332	1,366	2,083
Matls.	488	366	1,859	229	229	Not reported
Tooling	8,395	263	203	6,596	220	Not reported
Total	14,465	2,322	6,462	11,157	1,815	Not reported

* 1,515 with bleed holes and seal ring groove deleted

** 3,842 with bleed holes and seal ring groove deleted

Complete Engine Assemblies: A number of ramjet engine cost estimates have been available through references (1), (2) and (17). A summary of these is presented in Table 25. During the buildup and checkout of the Vought Cost Methodology a number of miscellaneous engine costing exercises have also generated some cost data. In some cases, the costs were computed using the engine configuration and quantity specified in the reference documents (as well as they could be defined) to determine how close the cost estimates compared. The Vought cost estimates are presented in Table 26. Note that the costs are broken down by major sub-assembly to give some visibility of the key cost driver in the system cost.

A comparison of costs has been made between the two sets of estimates for the engines that are near matches in size and quantity. The "other" engine costs have been adjusted where necessary to 1976 costs by using the OSD Escalator Indices reported in reference (2). These comparisons are shown in Table 27.

Study of the table reveals that the Vought Methodology consistently predicts higher costs of the engine assemblies than any of the previously reported costs. The ratio of costs goes from 1.009 to 2.257, which on the surface does not appear to be a good correlation. There are several possible explanations:

1) The other estimates are overly optimistic.

2) The Vought costs include more components than the other estimates considered.

3) The other estimates were made on the basis of only conceptual definitions of hardware which were perhaps unrealistic for flight hardware.

It is believed that some of each of the above factors may account for the differences; however, it is not possible with the limited amount of data that is currently available to make a more thorough assessment.

One factor that was present in the comparisons was the lack of specific information on the ramjet engines that were previously costed. Information on structural materials, fuel controls, etc, were not always available. The Vought methodology required this data be included and it is possible that some different assumptions were made.

The disparity between estimates should not be of major concern. The important thing is that the methodology and the approach taken in the development of the methodology is sound. If production cost data becomes available that disproves some of the detail cost data generated by Vought for the baseline system, the baseline costs can be easily adjusted or modified in whatever manner is believed appropriate. It is Vought's belief that the cost numbers contained in this document and in the Cost Handbook are the best available to date, and should be used by the government and industry in projecting realistic production costs.

TABLE 25

MISCELLANEOUS RAMJET COST DATA

Engine No.	Ramjet	Diameter (Inches)	Quantity	System	Unit Cost ($)	Year	Cost Reference
(1)	LFRJ-IRR (Series)	9	1500	Booz-Allen Estimate	5,930	1973	In A. Victor Paper Ref. (2)
(2)		12	1500		7,907		
(3)		15	1500		10,572		
(4)	LFRJ (Med Cost)	17.5	3000	Worked example	34,463		A. Victor Paper
(5)	SFRJ-IRR	8.5	1500	Advanced Integrated Air to Air Missile (AIAAM) Study	6,680	1973	P.G. Fry, 1976 JANNAF Propulsion Meeting Vol. 5
(6)	SDR-IRR	8.5	1500		8,115		
(7)	LFRJ-IRR	8.5	1500		9,165		
(8)	LFRJ-IRR	12.5	5000	Low Cost Propulsion Integration Study MAC-DAC Program.	15,915	1975	Unpublished Data Informally Received From AFAPL.
(9)	SDR-IRR	12.5	5000		15,250		
(10)	SFRJ-IRR	12.5	5000		12,555		
(11)	LFRJ-IRR	8	5000		11,370		
(12)	SDR-IRR	8	5000		10,285		
(13)	SFRJ-IRR	8	5000		8,015		
(14)	LFRJ-IRR	6	5000		8,305		
(15)	SDR-IRR	6	5000		6,000		
(16)	SFRJ-IRR	6	5000		4,860		

TABLE 26

VOUGHT COST CALCULATIONS

ENGINE NO.	TYPE RAMJET	DIAMETER (IN.)	INLETS	QUANTITY	SUB ASSEMBLY COSTS SA		UNIT TOTAL COST($)
(1)	LFRJ-IRR	12	2	5000	Air Induct.	3,460	
					Boost/Comb	6,225	
					Fuel Mgt	5,630	
					Final Assy	2,028	17,343
(2)	SDR-IRR	6	2	5000	AI	2,140	
					B/C	3,637	
					FM	2,771	
					FA	935	9,483
(3)	LFRJ-IRR	15	4	1500	AI	9,076	
					*B/C	12,212	
					FM	9,825	
					FA	2,862	33,975
(4)	LFRJ-IRR	17.5	4	3000	AI	9,724	
					*B/C	17,992	
					FM	10,981	
					FA	2,989	41,686
(5)	SFRJ-IRR	8.5	2	1500	AI	4,144	
					B/C	5,502	
					FM	828	
					FA	1,339	11,813
(6)	LFRJ-IRR	12.5	4	5000	AI	6,048	
						6,383	
						7,021	
						2,148	21,600

*Includes thermal insulation cost.

TABLE 27

COMPARISON OF RAMJET ENGINE COST ESTIMATES

VOUGHT ENGINE NO.	ENGINE DESCRIPTION	QUANTITY	UNIT COST	COMPARED TO OTHER COST REPORTED ENGINE NO.	COST*	RATIO VOUGHT $/OTHER $
(1)	12" LFRJ-IRR	5000	17,343	(8)	17,189	1.009
(2)	6" SDR-IRR	5000	9,483	(15)	6,480	1.463
(3)	15" LFRJ-IRR	1500	33,975	(3)	15,212	2.233
(4)	17.5"LFRJ IRR	3000	41,686	(4)	34,463	1.210
(5)	8.5" SFRJ-IRR	1500	11,813	(5)	9,612	1.229
(6)	12.5" LFRJ-IRR	5000	21,600	(8)	17,189	1.257

* Adjusted to 1976 $

SECTION IV
POTENTIAL APPLICATION OF COST METHODOLOGY

The cost methodology developed during this program can be used in a number of ways to help the ramjet system analyst evaluate his ramjet concept. The methodology can be employed to identify major cost drivers, investigate cost sensitivity to design changes, support general costing for proposals and even be useful in cost/effectiveness trade studies.

Vought has had occasion to use the methodology to make some brief studies of ramjet components and configurations in connection with some of its advanced missile studies.

1. COST DRIVER STUDIES

The term cost driver is often used to denote a design feature of a component that is primarily responsible for making that component cost what it does. The reason for wanting to identify the cost driver of an assembly or subassembly of a system is to gain insight on why the costs are high (or low) and thereby be able to design a lower cost assembly. The cost methodology is able to show the variation in cost between designs as well as to identify the major cost factors at different production quantities. Figure 41 shows two different 2-dimensional inlet designs, both made of the same material. The cost breakdown on each of the inlets is shown in the tables at the bottom of the figure. A look at the tables reveals the following information.

(a) Tooling costs are obviously high for small quantities. If the production quantity is going to be small, considerable attention to reducing tooling costs can be very productive.

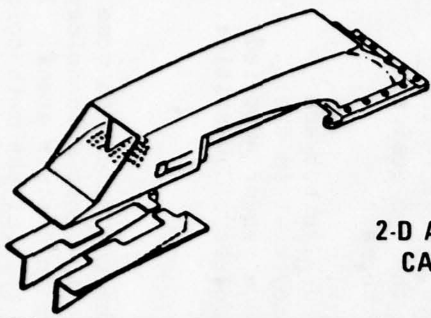
(b) Tooling costs become rather insignificant if quantities get out into the thousands or tens of thousands of units, so efforts to reduce tooling costs for large quantities is not very significant.

(c) Design variations greatly influence costs. Observe the variation in manufacturing cost between the two designs. There are obvious trade-offs that might be made.

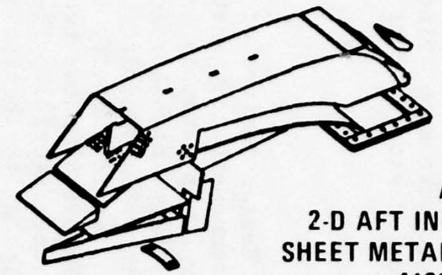
(d) Material costs are not important in one design but are extremely important in the other. The key cost in the one design is the large casting which is a vendor supplied part. This is a major cost factor regardless of quantities.

2. GENERAL COSTING OF PROPOSALS

Vought has recently made some proposals to the government on some ramjet missile development programs and was able to use the cost methodology to supplement or back up the independent cost estimates in certain areas. It is conceivable that the cost methodology or at least a part of the methodology could be used for estimating production hardware costs other than ramjet engines in much the same way that Vought used the Army Rocket Motor Computer program to develop cost data for ramjet components.



A-1-1
2-D AFT INLET ASSEMBLY
CAST CONSTRUCTION
4130 STEEL



A-1-2
2-D AFT INLET ASSEMBLY
SHEET METAL CONSTRUCTION
4130 STEEL

SYSTEM COMPONENT 1 A-1-1 – 2-D AFT INLET ASSY – CAST CONSTRUCTION

QUANTITY	1		10		100		1,000		5,000		10,000	
	$	%	$	%	$	%	$	%	$	%	$	%
TOOLING COST	166,577	93.2	16,658	62.7	1,666	18.6	400	6.5	133	2.4	83	1.5
MFG COST	4,841	2.7	3,389	12.8	1,752	19.5	968	15.7	799	14.4	764	14.1
MATERIAL COST	7,248	4.1	6,487	24.5	5,545	61.9	4,784	77.8	4,610	83.2	4,594	84.4
SELLING PRICE	178,666	100.0	26,533	100.0	8,963	100.0	6,152	100.0	5,542	100.0	5,441	100.0

SYSTEM COMPONENT 2 A-1-2 – 2-D AFT INLET ASSY – SHEET METAL CONSTRUCTION

QUANTITY	1		10		100		1,000		5,000		10,000	
	$	%	$	%	$	%	$	%	$	%	$	%
TOOLING COST	98,013	91.9	9,801	61.9	980	23.8	235	11.8	78	5.1	49	3.4
MFG COST	8,555	8.0	5,989	37.8	3,097	75.1	1,711	86.1	1,412	92.3	1,351	93.8
MATERIAL COST	63	0.1	56	0.3	48	1.1	42	2.1	40	2.6	40	2.8
SELLING PRICE	106,631	100.0	15,846	100.0	4,125	100.0	1,988	100.0	1,530	100.0	1,440	100.0

FIGURE 41 VARIATION IN COST ELEMENTS WITH QUANTITY

3. COST/EFFECTIVENESS STUDIES

In many instances it is desirable to know the relationship between system performance and cost. As an example, Vought has been conducting in-house studies of LFRJ-powered missiles to perform certain missions. A baseline system design was established and its basic performance characteristics determined. Performance trade studies were conducted for small variations in the missile design using conventional aerodynamic and propulsion analysis techniques; however, it was also of interest to know what impact these variations had on cost--both RDT and E cost and Production Cost. The Vought ramjet cost methodology was employed to show the expected variation. Table 28 shows the results of the cost analysis.

TABLE 28

LFRJ ENGINE PRODUCTION COST SUMMARY IN 1977 DOLLARS

	1	2	3	4	5 (BASELINE)	6	7	8	9
Booster Diameter	15.5	15.5	15.5	15.5	15.5	15.5	17.0	17.0	17.0
Fuel Tank Diameter	15.0	15.0	15.0	15.5	15.5	15.5	17.0	17.0	17.0
Vehicle Length	169	179	189	169	179	189	169	179	189
Capture Area/Inlet	18	18	18	18	18	18	23	23	23
Booster Case Length	43.3	44.5	45.8	44.2	45.9	47.6	39.7	41.3	42.9
Fuel Tank Case Length	54.5	63.3	72.0	54.9	63.2	71.4	57.4	65.9	74.2
FMS Compartment Length	8.5	8.5	8.5	8.8	8.8	8.8	9.6	9.6	9.6

1977 $ Cumulative Average Cost for 2000 Production Units

	1	2	3	4	5 (BASELINE)	6	7	8	9
Air Induction Sys. Cost	2650	2650	2650	2650	2650	2650	2950	2950	2950
Booster/Combustor Cost	18700	18850	19050	18900	19000	19200	20150	20550	20800
Fuel System Cost	12150	12300	12450	12450	12600	12750	13800	14050	14150
Final Assembly Cost	2850	2850	2850	2900	2900	2900	3200	3200	3200
Total RJ Engine Cost	36350	36650	37000	36900	37150	37500	40100	40750	41100
Cost from Baseline	- 800	- 500	- 150	- 250	0	350	2950	3600	3950
% Deviation from Baseline	- 2.1	- 1.34	- .40	- .67	0	.94	7.94	9.69	10.63

SECTION V
CONCLUSIONS AND RECOMMENDATIONS

This program has attempted to advance the status of ramjet cost estimating techniques by the establishment of a significantly large cost data base and the generation of a handbook-type methodology to use the data base for predicting costs of ramjets. The methodology and data base are applicable to a large number of ramjet types and configurations and can handle variations in size, production quantities and production rates.

The methodology has been designed to be used by cost estimators with only limited knowledge of ramjet engines. It is judged to be fast, simple to use, flexible and accurate.

The methodology is published in a separate volume called "The Ramjet Production Cost Handbook." The handbook is also published in loose leaf form in order to facilitate the working of the handbook and to allow for future additions as new cost data become available.

The methodology has been checked by working some sample problems, and it has been used by Vought in some related missile cost/effectiveness and cost driver studies. There are areas where the methodology can be improved. Several things are specifically recommended. One is the computerization of the data base and the cost computation. Another is the expansion of the data base, and the third is the addition of some general engine performance predictions capability.

1. COMPUTERIZATION OF COST METHODOLOGY

The current methodology has been designed to produce the cost of a specific ramjet engine configuration in approximately 2 to 4 hours using tables, curves, and quadratic equations contained in a handbook. In certain studies, it is often desirable to investigate the impact of slight variations in the design--such as alternate manufacturing processes, configurations, materials, or even sizes on cost variations. However, it would be very time consuming to make a complete analysis of a number of variables unless the computations can be automated by a rather simple computer program.

The computerization of the program would allow a rapid assessment of a large number of configurations and design variables. It would provide a valuable tool in a "Design-to-Cost" study of ramjet engines. It could be used to identify which components were the primary cost drivers under certain situations as well as identifying why they were the cost drivers (labor, materials, tooling, etc.).

The basic cost methodology lends itself quite well to computer implementation since it is founded on a building block approach. The generation of a routine to manipulate the basic computations and to store the baseline cost data can be accomplished with a nominal amount of time.

2. EXPANSION OF COST DATA BASE

The current program has resulted in the identification and costing of around 130 specific components many of which are constructed of three different materials making a total of around 300 basic components that make up the baseline data base for the cost handbook. This number was the result of a compromise between time and money available on the contract and the virtually unlimited configurations, materials, and manufacturing processes that are possible candidates for ramjet engines.

The present data base for components is a spin-off of the Vought designed and built ALVRJ Liquid Fueled Integral Rocket/Ramjet. Consequently, most of the baseline components are basically designed for a 15-inch diameter engine. The costing methodology provides for a scaling up or down of the baseline components' costs to cover a range of engine diameters from a nominal 6 inches to 18 inches. While the approach is basically sound, there are some aspects of the costing which it does not consider--that being the possibility of component "redesign" to take advantage of manufacturing processes or stock materials that could result in more simple designs and consequently less expensive manufacturing costs. This is particularly true for the smaller engine sizes where stock tubing might be substituted for a rolling and welding operation using sheet stock materials. In similar manner, many components involving the joining of many small parts like an inlet assembly might be redesigned to eliminate a large number of individual parts by combining subcomponents and parts or combining assembly operations.

An expansion of the components data base to include additional configurations, manufacturing processes, and material of construction would provide a broader spectrum of choices for the cost handbook user in attempting to relate his specific design to components listed in the handbook. It would result in higher confidence in the cost estimating because it would require less approximating on the cost equivalence between components of slightly differing designs. In addition, a fresh look should be given to the component data base to determine if smaller engines are being unnecessarily penalized by simply scaling down a 15" diameter engine component. If it is apparent that the smaller engines can be produced with more simple designs, an adjustment should be made to the predicted costs to account for this. The net result should be the generation of more realistic costs for the smaller engines.

A "design-to-cost" type study of the baseline components should be made to determine where fabrication processes and materials might be modified slightly to accommodate the small (6 to 10 inch diameter) engine. If it is determined that there is a special relationship that exists between size and design simplification and therefore cost reduction, this relationship should be established. The review should concentrate on the high cost components and the fabricated components like inlets, combustors, nozzles, and fuel tanks.

3. SUPPLEMENTAL PERFORMANCE DATA

Air Force tactical missile requirements of the future may impose weight, range, speed and maneuverability requirements on propulsion systems that can only be met with ramjet propulsion systems. Many of the systems analysis engineers are reluctant to evaluate ramjet engines for their mission

studies because they do not have sufficient knowledge of the performance potential or the cost of ramjet engines. The current program will provide a tool that can be used to generate good cost numbers if the user has already determined the size and design/construction features of a particular ramjet propulsion system. There is still lacking a method by which the user can determine the configuration of a ramjet which can potentially satisfy specified mission requirements.

It is possible to create a section of the cost methodology handbook which will permit the user to readily obtain reasonable approximations of range, weight, and ramjet engine cost with a minimum of required input information.

Use of an existing Vought computer routine can be made to generate parametric performance data based upon typical inputs. Inputs which are judged to have the least effect on results will be assigned typical values and will remain constant for the analyses. Inputs which are judged to have the greatest impact on results will be assigned a range of values. This latter category will consist of missile diameter, engine length, nonpropulsive weight, ramjet type, and trajectory. The variables have been necessarily limited in order to achieve an approach which will produce reasonable accuracy at minimum program cost. A summary of the recommended study configurations and assumptions is included in Table 29. The output data could be displayed as parametric graphs, tables, or equations and could be organized such that the user is not required to be knowledgeable in ramjet technology status or limits.

TABLE 29 INPUT/OUTPUT PARAMETERS

Ramjet types to be considered:

- LFRJ
- SFRJ — All will be integral rocket ramjet
- SDR

Input Parameters having constant values:

- EOB M_N = 2.0 @ S.L. @ Launch M_N = .7 for Design
- Inlet Design Mach No. = 2.0 (Two Aft Mounted 2-D Inlets)
- 6% Inlet Pressure Recovery at Takeover Mach NO.
- 15% Thrust Margin at Ramjet Takeover Mach No.
- 2.5:1 Von Karman Nose with 5% Bluntness
- Ejectable Booster Nozzle Insert
- Inlet Covers During Boost
- A_6/A_3 = .95
- A_C/A_3, A_5/A_3, T_{T4} for Min. SFC
- LFRJ Fuel Control is F/A - Const. with Pres. Rec. Margin and M_N Bias
- Best Available Models for Nozzle and Combustion Efficiencies
- Boost Propellant: HTPB Low Smoke with C* - 4920, P_C - 1000 PSIA
- Sustain Propellants:

  LFRJ - Shelldyne
  SFRJ - HTPB Low Smoke
  SDR - Hydrocarbon

Program Outputs

- Range
- Average Velocity
- Missile Weight
- Engine Cost

Input Parameters having range of values:

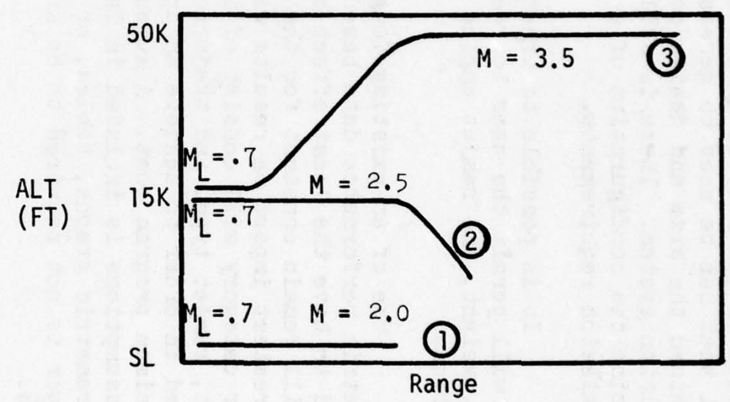
- Missile Diameters 6, 12, and 18 inches
- Engine Lengths

  65, 75, 85 @ 6 inches dia.
  65, 75, 85 @ 12 inches dia.
  85, 100, 115 @ 18 inches ida.

- Non-Propulsive Weights (including Payload)

  75, 100, 125 @ 6 inches dia.
  300, 400, 500 @ 12 inches dia.
  800, 1000, 1200 @ 18 inches dia.

- Trajectories (3 Typical)



APPENDIX

BASELINE COMPONENT COST ESTIMATES

UNIT NO. 1 COST

TABLE 1-1. BASELINE COMPONENT COST ESTIMATES – UNIT NO. 1

(PRIME CONTRACTOR MANUFACTURED)

STRUCTURAL MATERIAL 17-4 STAINLESS STEEL

COMPONENT	(1) PRODUCTION MANHOURS	(2) PRODUCTION COST	(3) TOOLING MANHOURS	(4) TOOLING LABOR COST	(5) TOOLING MATERIALS NON-RECURRING	(6) PURCHASED TOOLING COST	(7) TOTAL TOOLING COST (4) + (6)	(8) MATERIALS RECURRING	(9) PURCHASED MATERIALS RECURRING COST	(10) SELLING PRICE (2) + (7) + (9)
A-1 INLET ASSEMBLIES										
A-1-1 2-D AFT INLET ASSEMBLY - CAST	122.7	4,238	751	25,205	85,000	125,215	150,420	2,477	3,894	158,552
A-1-2 2-D AFT INLET ASSEMBLY - SHEET METAL	181.9	6,283	2,408	81,686	--	--	81,686	120	189	88,158
A-1-3 AXISYMMETRIC AFT INLET ASSEMBLY - CAST	27.9	964	2,345	79,538	52,524	77,374	156,912	915	1,438	159,314
A-1-4 AXISYMMETRIC AFT INLET ASSEMBLY - SHEET METAL	133.6	4,615	2,984	101,319	--	--	101,319	260	408	106,342
A-1-5 CHIN INLET ASSEMBLY - CAST/SHEET METAL	165.8	5,727	5,116	173,990	122,000	179,721	353,711	5,903	9,281	368,719
A-1-6 CHIN INLET ASSEMBLY - SHEET METAL	725.7	25,066	10,495	357,339	--	--	357,339	651	1,024	383,429
A-1-7 AXISYMMETRIC PODDED INLET ASSEMBLY - CAST/SHEET METAL	128.2	4,428	1,124	37,919	14,000	20,624	58,543	1,099	1,728	64,699
A-1-8 PITOT PODDED INLET ASSEMBLY - SHEET METAL	94.7	3,271	374	12,355	--	--	12,355	69	108	15,734
A-2 INLET AFT FAIRINGS										
A-2-1 2-D AFT INLET AFT FAIRING	56.8	1,962	699	23,432	--	--	23,432	61	96	25,490
A-2-2 AXISYMMETRIC AFT INLET AFT FAIRING	57.4	1,983	699	23,432	--	--	23,432	74	116	25,531
A-2-3 CHIN INLET AFT FAIRING	53.2	1,838	2,817	95,627	3,000	4,419	100,046	457	719	102,603
A-3 INLET SIDE FAIRINGS										
A-3-1 2-D AFT INLET SIDE FAIRING	41.2	1,423	447	14,843	--	--	14,843	70	110	16,376
A-3-2 AXISYMMETRIC AFT INLET SIDE FAIRING	42.1	1,454	447	14,843	--	--	14,843	68	107	16,404
A-4 POD ATTACH FAIRING	80.5	2,780	850	28,580	--	--	28,580	213	335	31,695
A-5 OPTIONS										
A-5-1 2-D INLET COVER	29.2	1,009	586	19,581	--	--	19,581	486	764	21,354
A-5-2 AXISYMMETRIC INLET COVER	27.8	960	989	33,317	--	--	33,317	477	750	35,027
A-5-3 CHIN INLET COVER	32.5	1,123	1,119	37,749	3,000	4,419	42,168	470	739	44,030
A-5-4 AIRFOIL TYPE AERODYNAMIC GRID - 2-D	7.1	245	280	9,150	3,000	4,419	13,569	44	69	13,883
A-5-5 AIRFOIL TYPE AERODYNAMIC GRID - CIRCULAR	6.4	221	145	4,549	4,000	5,892	10,441	66	104	10,766
B-1 COMBUSTOR CHAMBER ASSEMBLY (INTEGRAL OR NON-INTEGRAL DESIGN)										
B-1-1 CHAMBER FOR AFT INLET DESIGN (LFRJ)										
B-1-1-1 ROLL AND WELD CONSTRUCTION	355.4	12,276	5,396	183,534	6,200	9,133	192,667	519	816	205,759
B-1-1-2 DEEP DRAW CONSTRUCTION	231.9	8,010	4,280	145,494	86,200	126,983	272,477	806	1,267	281,754
B-1-1-3 MACHINED & SHEAR SPUN CONSTRUCTION	633.8	21,891	7,645	260,194	18,200	26,811	287,005	2,299	3,614	312,510
B-1-2 CHAMBER FOR CHIN INLET DESIGN (LFRJ)										
B-1-2-1 ROLL AND WELD CONSTRUCTION	163.2	5,637	1,932	65,460	--	--	65,460	168	264	71,361
B-1-2-2 DEEP DRAW CONSTRUCTION	87.9	3,036	1,546	52,303	52,000	76,602	128,905	514	808	132,749
B-1-2-3 MACHINED & SHEAR SPUN CONSTRUCTION	429.2	14,825	6,540	222,529	12,000	17,677	240,206	1,425	2,240	257,271

TABLE 1-1. BASELINE COMPONENT COST ESTIMATES – UNIT NO. 1

STRUCTURAL MATERIAL 17-4 STAINLESS STEEL

COMPONENT	(1) PRODUCTION MANHOURS	(2) PRODUCTION COST	(3) TOOLING MANHOURS	(4) TOOLING LABOR COST	(5) TOOLING MATERIALS NON RECURRING	(6) PURCHASED TOOLING COST	(7) TOTAL TOOLING COST (4) + (6)	(8) MATERIALS RECURRING	(9) PURCHASED MATERIALS RECURRING COST	(10) SELLING PRICE (2) + (7) + (9)
B-1-3 CHAMBER FOR PODDED DESIGN (LFRJ) ROLL & WELD	114.2	3,944	899	30,250	--	--	30,250	146	230	34,424
B-1-4 CHAMBER FOR AFT INLET DESIGN (SFRJ)										
B-1-4-1 ROLL AND WELD CONSTRUCTION	337.4	11,654	5,269	179,206	26,200	38,596	217,802	582	915	230,371
B-1-4-2 DEEP DRAW CONSTRUCTION	284.0	9,809	4,981	169,399	26,200	38,596	207,965	667	1,049	218,823
B-1-4-3 MACHINED AND SHEAR SPUN CONSTRUCTION	711.2	24,565	9,136	311,016	22,200	32,703	343,719	2,022	3,17[illegible]	371,462
B-1-5 CHAMBER FOR AFT INLET DESIGN (SFDR OR LFDR)										
B-1-5-1 ROLL AND WELD CONSTRUCTION	365.4	12,621	5,591	190,181	6,200	9,133	199,314	555	873	212,808
B-1-5-2 DEEP DRAW CONSTRUCTION	246.2	8,504	4,540	154,357	86,200	126,983	281,340	842	1,324	291,168
B-1-5-3 MACHINED AND SHEAR SPUN CONSTRUCTION	625.1	21,591	7,645	260,194	18,200	26,811	287,005	2,299	3,614	312,210
B-2 BOOSTER CHAMBER ASSEMBLY (FOR NON-INTEGRAL BOOSTER ONLY)										
B-2-1 STAGED (SEPARABLE)										
B-2-1-1 ROLL AND WELD CONSTRUCTION	303.6	10,486	2,569	87,173	--	--	87,173	656	1,031	98,690
B-2-1-2 DEEP DRAW CONSTRUCTION	238.5	8,238	2,167	73,471	29,000	42,720	116,191	915	1,438	125,867
B-2-2 NON-STAGED										
B-2-2-1 ROLL AND WELD CONSTRUCTION	201.3	6,953	2,523	85,605	--	--	85,605	217	341	92,899
B-2-2-2 DEEP DRAW CONSTRUCTION	189.0	6,528	2,121	71,903	29,000	42,720	114,623	476	748	121,899
B-3 SUSTAINER NOZZLE ASSEMBLY										
B-3-1 SILICA PHENOLIC INSERT	163.6	5,651	1,797	60,859	5,375	7,918	68,777	713	1,121	75,549
B-3-2 METALLIC/SILICA PHENOLIC	222.2	7,675	2,281	77,356	2,400	3,535	80,891	652	1,025	89,591
B-7 BOOSTER NOZZLE ASSEMBLY										
B-7-1 NOZZLE FOR INTEGRAL DESIGN										
B-7-1-1 SILICA PHENOLIC WITH GRAPHITE THROAT	67.1	2,318	613	20,501	--	--	20,501	337	530	23,349
B-7-1-2 SILICA PHENOLIC WITH METALLIC STRUCTURE #1	77.5	2,677	613	20,501	--	--	20,501	456	717	23,895
B-7-2 NOZZLE FOR NON-INTEGRAL BOOSTER										
B-7-2-1 SILICA PHENOLIC/METAL/GRAPHITE	197.9	6,835	1,411	47,702	--	--	47,701	317	498	55,034
B-8 BOOSTER NOZZLE RETENTION ASSEMBLY (INTEGRAL)										
B-8-1 BOOSTER NOZZLE RETENTION ASSEMBLY (INTEGRAL)	16.7	577	192	6,151	--	--	6,151	23	36	6,764
B-8-2 BOOSTER NOZZLE ATTACH CLAMP ASSEMBLY (INTEGRAL)	29.1	1,005	555	18,524	--	--	18,524	165	259	19,788
B-9 BOOSTER ATTACH CLAMP ASSEMBLY (NON-INTEGRAL)	29.1	1,005	555	18,524	--	--	18,524	165	259	19,788
B-11 CASE PORT COVER (ALUMINUM)	1.7	59	292	9,559	3,600	5,303	14,862	42	66	14,987
B-12 AFT SHROUD (NON-INTEGRAL BOOSTER)	70.6	2,439	525	17,501	--	--	17,501	68	107	20,047

TABLE 1-1. BASELINE COMPONENT COST ESTIMATES – UNIT NO. 1

STRUCTURAL MATERIAL 17-4 STAINLESS STEEL

COMPONENT	(1) PRODUCTION MANHOURS	(2) PRODUCTION COST	(3) TOOLING MANHOURS	(4) TOOLING LABOR COST	(5) TOOLING MATERIALS NON-RECURRING	(6) PURCHASED TOOLING COST	(7) TOTAL TOOLING COST (4) + (6)	(8) MATERIALS RECURRING	(9) PURCHASED MATERIALS RECURRING COST	(10) SELLING PRICE (2) + (7) + (9)
B-13 BOOSTER/COMBUSTOR OPTIONS										
B-13-1 FIXED LAUNCH RAIL (1 FITTING)	9.0	311	281	9,184	2,652	3,907	13,091	42	66	13,468
B-13-2 EXTERNAL FOLDING LAUNCH LUG	28.2	974	626	20,944	6,222	9,166	30,110	129	203	31,287
B-13-3 FOLDING LAUNCH LUG/SWAY BRACE/FAIRING SUPPORT	59.2	2,045	691	23,160	14,200	20,918	44,078	468	735	46,858
B-13-4 360° & 180° SWAY BRACE OR SUPPORT	27.5	950	329	10,821	--	--	10,821	45	71	11,842
B-13-7 STRONGBACK	14.2	490	145	4,549	--	--	4,549	33	52	5,091
C-4 FUEL TANK - LFRJ										
C-4-1 FUEL TANK WITH STANDPIPE AND FULL BLADDER										
C-4-1-1 ROLL AND WELD CONSTRUCTION	363.7	12,562	2,150	72,891	9,900	14,584	87,475	1,330	2,091	102,128
C-4-1-2 DEEP DRAW CONSTRUCTION	261.0	9,015	2,397	81,310	38,900	57,304	138,614	1,589	2,498	150,127
C-4-1-3 MACHINED FORGING WITH ROLL AND WELD CASE	366.2	12,649	2,239	75,925	9,900	14,584	90,509	2,052	3,226	106,384
C-4-1-4 MACHINED AND SHEAR SPUN CONSTRUCTION	359.8	12,427	2,831	96,104	9,900	14,584	110,688	2,669	4,196	127,311
C-4-2 FUEL TANK WITH HALF ROLLING DIAPHRAGM	431.6	14,907	2,246	76,164	4,000	5,892	82,056	1,113	1,750	98,713
C-5 PROPELLANT/OXIDIZER TANKS (LDR) (REF. C-4, LDR LIQUID FUEL AND OXIDIZER TANKS ARE SAME AS LFRJ LIQUID FUEL TANKS)										
C-8 FUEL MANIFOLDS AND INJECTORS										
C-8-1 WALL MOUNTED INJECTORS IN INLET PADS (PER INLET)	10.5	363	281	9,185	--	--	9,185	32	50	9,598
C-8-2 WALL MOUNTED INJECTORS AROUND INLET DUCT	114.4	3,951	429	14,229	--	--	14,229	77	121	18,301
C-8-3 INTERNAL STREAM INJECTORS (PER INLET)	19.2	663	476	15,831	3,500	5,156	20,987	120	189	21,839
C-8-4 INTERNAL STREAM INJECTOR FOR PODDED RAMJET	167.8	5,796	1,922	65,120	--	--	65,120	121	190	71,106
C-9 FUEL MANAGEMENT SYSTEM COMPARTMENT	170.0	5,872	284	9,287	--	--	9,287	93	146	15,305
C-10 GAS GENERATOR - LRDR	116.7	4,031	1,052	35,465	3,000	4,419	39,884	250	393	44,308
C-11 GAS GENERATOR NOZZLE	82.2	2,839	832	27,966	--	--	27,966	387	608	31,413
C-12 RAM AIR TURBINE SCOOP	18.6	642	384	12,695	4,500	6,629	19,324	380	597	20,563
C-13 FUEL SYSTEM OPTIONS										
C-13-1 FUEL TANK FIXED LAUNCH RAIL (1 FITTING)	9.0	311	281	9,184	2,652	3,907	13,091	42	66	13,468
C-13-2 FUEL TANK EXTERNAL FOLDING LAUNCH LUG	28.2	974	626	20,944	6,222	9,166	30,110	129	203	31,287
C-13-3 SUBMERGED FOLDING LAUNCH LUG AND TANK SWAY BRACE	88.8	3,067	854	28,715	16,500	24,306	53,021	492	774	56,862
C-13-4 FMS COMPARTMENT SUBMERGED FOLDING LAUNCH LUG	36.0	1,243	626	20,944	6,222	9,166	30,110	129	203	31,556
C-13-5 FUEL TANK FOLDING LAUNCH LUG/SWAY BRACE/FAIRING SUPPORT	59.2	2,045	691	23,160	14,200	20,918	44,078	468	735	46,858
C-13-6 360° & 180° SWAY BRACE OR SUPPORT	27.5	950	329	10,821	--	--	10,821	45	71	11,842
C-13-7 FUEL TANK STRONGBACK	14.2	490	145	4,549	--	--	4,549	33	52	5,091

TABLE 1-1. BASELINE COMPONENT COST ESTIMATES – UNIT NO. 1

STRUCTURAL MATERIAL 17-4 STAINLESS STEEL

COMPONENT	(1) PRODUCTION MANHOURS	(2) PRODUCTION COST	(3) TOOLING MANHOURS	(4) TOOLING LABOR COST	(5) TOOLING MATERIALS NON RECURRING	(6) PURCHASED TOOLING COST	(7) TOTAL TOOLING COST (4) + (6)	(8) MATERIALS RECURRING	(9) PURCHASED MATERIALS RECURRING COST	(10) SELLING PRICE (2) + (7) + (9)
C-13-8 PODDED ENGINE MOUNT LUG	16.6	573	464	15,422	--	--	15,422	98	154	16,149
C-13-9 EXTERNAL INSULATION	17.7	611	6	195	--	--	195	59	93	899
C-13-10 WIRING & PLUMBING TUNNEL	22.5	777	1,312	44,327	--	--	44,327	58	91	45,195
D-3 GAS GENERATOR CHAMBER ASSEMBLY (SFDR)										
D-3-1 ROLL AND WELD CONSTRUCTION	293.3	10,131	2,833	96,172	--	--	96,172	318	500	106,803
D-3-2 DEEP DRAW CONSTRUCTION	222.0	7,668	2,447	83,015	52,000	76,602	159,617	664	1,044	168,329
D-3-3 MACHINED AND SHEAR SPUN CONSTRUCTION	341.5	11,795	2,496	84,685	12,000	17,677	102,362	1,468	2,308	116,465
D-4 SOLID DUCTED ROCKET NOZZLE ASSEMBLY	82.2	2,839	832	27,966	--	--	27,966	387	608	31,413
D-5 SOLID FUEL SYSTEM OPTIONS										
D-5-1 FIXED LAUNCH RAIL (1 FITTING)	9.0	311	281	9,185	2,652	3,902	13,092	42	66	13,468
D-5-2 EXTERNAL FOLDING LAUNCH LUG	28.2	974	626	20,944	6,222	9,166	30,110	129	203	31,287
D-5-3 FOLDING LAUNCH LUG/SWAY BRACE/FAIRING SUPPORT	59.2	2,045	691	23,160	14,200	20,918	44,078	468	735	46,858
D-5-4 360° & 180° SWAY BRACE OR SUPPORT	27.5	950	329	10,821	--	--	10,821	45	71	11,842
D-5-5 STRONGBACK	14.2	490	145	4,549	--	--	4,549	33	52	5,091
FINAL ASSEMBLY (DOES NOT INCLUDE SYSTEMS CHECKOUT)										
E-1 LIQUID FUEL RAMJET - INTEGRAL ROCKET - RAMJET	160.8	5,554	3,240	110,045	--	--	110,045	1,521	2,391	117,990
E-2 LIQUID FUEL RAMJET - STAGED BOOSTER	184.8	6,383	3,240	110,045	--	--	110,045	2,042	3,210	119,638
E-3 LIQUID FUEL RAMJET - PODDED	154.3	5,330	3,743	127,190	--	--	127,190	2,604	4,094	136,614
E-4 SOLID FUEL RAMJET - INTEGRAL ROCKET - RAMJET	105.7	3,651	2,818	95,661	--	--	95,661	1,304	2,050	101,362
E-5 SOLID FUEL DUCTED ROCKET - INTEGRAL ROCKET - RAMJET	127.5	4,404	3,204	108,818	--	--	108,818	1,304	2,050	115,272
E-6 SOLID FUEL DUCTED ROCKET - STAGED BOOSTER	153.6	5,305	3,204	108,818	--	--	108,818	1,824	2,868	116,991
E-7 LIQUID FUEL DUCTED ROCKET - INTEGRAL ROCKET - RAMJET	192.2	6,639	3,204	108,818	--	--	108,818	1,611	2,533	117,990
E-8 LIQUID FUEL DUCTED ROCKET - STAGED BOOSTER	229.2	7,917	3,240	110,045	--	--	110,045	2,132	3,352	121,314

TABLE 1-2. BASELINE COMPONENT COST ESTIMATES – UNIT NO. 1

STRUCTURAL MATERIAL 4130 STEEL

COMPONENT	(1) PRODUCTION MANHOURS	(2) PRODUCTION COST	(3) TOOLING MANHOURS	(4) TOOLING LABOR COST	(5) TOOLING MATERIALS NON-RECURRING	(6) PURCHASED TOOLING COST	(7) TOTAL TOOLING COST (4) + (6)	(8) MATERIALS RECURRING	(9) PURCHASED MATERIALS RECURRING COST	(10) SELLING PRICE (2) + (7) + (9)
A-1 INLET ASSEMBLIES										
A-1-1 2-D AFT INLET ASSEMBLY - CAST	114.0	3,938	999	33,658	85,000	125,215	158,873	3,467	5,452	168,263
A-1-2 2-D AFT INLET ASSEMBLY - SHEET METAL	191.9	6,628	2,887	98,013	--	--	98,013	37	58	104,694
A-1-3 AXISYMMETRIC AFT INLET ASSEMBLY - CAST	31.0	1,071	2,916	99,001	52,524	77,374	176,375	1,642	2,581	180,027
A-1-4 AXISYMMETRIC AFT INLET ASSEMBLY - SHEET METAL	167.9	5,799	3,434	116,658	--	--	116,658	81	127	122,584
A-1-5 CHIN INLET ASSEMBLY - CAST/SHEET METAL	181.4	6,266	5,406	183,875	122,000	179,721	363,596	8,507	13,375	383,237
A-1-6 CHIN INLET ASSEMBLY - SHEET METAL	757.9	26,178	12,740	433,862	--	--	433,862	202	317	460,357
A-1-7 AXISYMMETRIC PODDED INLET ASSEMBLY - CAST/SHEET METAL	130.2	4,497	1,368	46,236	14,000	20,624	66,860	1,409	2,215	73,572
A-1-8 PITOT PODDED INLET ASSEMBLY - SHEET METAL	98.0	3,385	374	12,354	--	--	12,354	21	34	15,773
A-2 INLET AFT FAIRINGS										
A-2-1 2-D AFT INLET AFT FAIRING	54.6	1,886	909	30,590	--	--	30,590	20	31	32,507
A-2-2 AXISYMMETRIC AFT INLET AFT FAIRING	54.6	1,886	909	30,590	--	--	30,590	23	36	32,512
A-2-3 CHIN INLET AFT FAIRING	52.4	1,810	2,817	95,627	3,000	4,419	100,046	209	328	102,184
A-3 INLET SIDE FAIRINGS										
A-3-1 2-D AFT INLET SIDE FAIRING	40.0	1,382	673	22,546	--	--	22,546	22	34	23,962
A-3-2 AXISYMMETRIC AFT INLET SIDE FAIRING	40.9	1,413	673	22,546	--	--	22,546	21	33	23,992
A-4 POD ATTACH FAIRING	78.2	2,701	850	28,580	--	--	28,580	66	103	31,384
A-5 OPTIONS										
A-5-1 2-D INLET COVER	28.1	971	586	19,581	--	--	19,581	338	532	21,084
A-5-2 AXISYMMETRIC INLET COVER	26.7	922	989	33,317	--	--	33,317	336	528	34,767
A-5-3 CHIN INLET COVER	31.0	1,070	1,119	37,749	3,000	4,419	42,168	388	610	43,848
A-5-4 AIRFOIL TYPE AERODYNAMIC GRID - 2-D	8.5	294	280	9,150	3,000	4,419	13,569	66	104	13,967
A-5-5 AIRFOIL TYPE AERODYNAMIC GRID - CIRCULAR	5.8	200	145	4,549	4,000	5,892	10,441	99	156	10,797
B-1 COMBUSTOR CHAMBER ASSEMBLY (INTEGRAL OR NON-INTEGRAL DESIGN)										
B-1-1 CHAMBER FOR AFT INLET DESIGN (LFRJ)										
B-1-1-1 ROLL AND WELD CONSTRUCTION	369.8	12,773	6,581	223,926	6,200	9,133	233,059	548	861	246,693
B-1-1-2 DEEP DRAW CONSTRUCTION	241.3	8,335	4,893	166,389	66,200	97,520	263,909	633	995	273,239
B-1-1-3 MACHINED & SHEAR SPUN CONSTRUCTION	616.0	21,277	8,396	285,792	18,200	26,811	312,603	1,453	2,284	336,164
B-1-2 CHAMBER FOR CHIN INLET DESIGN (LFRJ)										
B-1-2-1 ROLL AND WELD CONSTRUCTION	165.3	5,709	2,191	74,289	--	--	74,289	52	83	80,081
B-1-2-2 DEEP DRAW CONSTRUCTION	91.1	3,147	1,805	61,132	52,000	76,602	137,734	155	244	141,125
B-1-2-3 MACHINED & SHEAR SPUN CONSTRUCTION	406.3	14,034	7,291	248,127	12,000	17,677	265,804	730	1,148	280,986

TABLE 1-2. BASELINE COMPONENT COST ESTIMATES – UNIT NO. 1

STRUCTURAL MATERIAL 4130 STEEL

COMPONENT	(1) PRODUCTION MANHOURS	(2) PRODUCTION COST	(3) TOOLING MANHOURS	(4) TOOLING LABOR COST	(5) TOOLING MATERIALS NON RECURRING	(6) PURCHASED TOOLING COST	(7) TOTAL TOOLING COST (4) + (6)	(8) MATERIALS RECURRING	(9) PURCHASED MATERIALS RECURRING COST	(10) SELLING PRICE (2) + (7) + (9)
B-1-3 CHAMBER FOR PODDED DESIGN (LFRJ) ROLL & WELD	121.0	4,179	1,319	44,566	--	--	44,566	46	72	48,817
B-1-4 CHAMBER FOR AFT INLET DESIGN (SFRJ)										
B-1-4-1 ROLL AND WELD CONSTRUCTION	351.0	12,124	6,454	219,597	26,200	38,596	258,193	567	891	271,208
B-1-4-2 DEEP DRAW CONSTRUCTION	299.2	10,334	5,594	190,284	21,200	31,230	221,514	634	997	232,845
B-1-4-3 MACHINED AND SHEAR SPUN CONSTRUCTION	690.5	23,850	10,321	351,408	22,200	32,703	384,111	1,327	2,086	410,047
B-1-5 CHAMBER FOR AFT INLET DESIGN (SFDR OR LFDR)										
B-1-5-1 ROLL AND WELD CONSTRUCTION	381.1	13,163	6,776	230,573	6,200	9,133	239,706	559	879	253,746
B-1-5-2 DEEP DRAW CONSTRUCTION	254.7	8,797	5,153	175,252	66,200	97,520	272,772	644	1,012	282,581
B-1-5-3 MACHINED AND SHEAR SPUN CONSTRUCTION	607.8	20,993	8,396	285,792	18,200	26,811	312,603	1,450	2,280	335,876
B-2 BOOSTER CHAMBER ASSEMBLY (FOR NON-INTEGRAL BOOSTER ONLY)										
B-2-1 STAGED (SEPARABLE)										
B-2-1-1 ROLL AND WELD CONSTRUCTION	308.8	10,666	2,828	96,002	--	--	96.002	202	317	106,985
B-2-1-2 DEEP DRAW CONSTRUCTION	245.6	8,483	2,426	82,299	29,000	42,720	125,019	364	572	134,074
B-2-2 NON-STAGED										
B-2-2-1 ROLL AND WELD CONSTRUCTION	217.4	7,509	2,782	94,434	--	--	94,434	67	105	102,048
B-2-2-2 DEEP DRAW CONSTRUCTION	201.6	6,963	2,380	80,731	29,000	42,720	123,451	229	360	130,774
B-3 SUSTAINER NOZZLE ASSEMBLY										
B-3-1 SILICA PHENOLIC INSERT	168.4	5,817	2,003	67,880	5,375	7,918	75,798	560	881	82,496
B-3-2 METALLIC/SILICA PHENOLIC	218.3	7,540	2,490	84,480	2,400	3,535	88,015	500	786	96,341
B-7 BOOSTER NOZZLE ASSEMBLY										
B-7-1 NOZZLE FOR INTEGRAL DESIGN										
B-7-1-1 SILICA PHENOLIC WITH GRAPHITE THROAT	67.1	2,318	613	20,501	--	--	20,501	337	530	23,349
B-7-1-2 SILICA PHENOLIC WITH METALLIC STRUCTURE #1	77.5	2,677	613	20,501	--	--	20,501	456	717	23,895
B-7-2 NOZZLE FOR NON-INTEGRAL BOOSTER										
B-7-2-1 SILICA PHENOLIC/METAL/GRAPHITE	198.8	6,867	1,620	54,826	--	--	54,826	259	407	62,100
B-8 BOOSTER NOZZLE RETENTION ASSEMBLY (INTEGRAL)										
B-8-1 BOOSTER NOZZLE RETENTION ASSEMBLY (INTEGRAL)	15.1	521	192	6,151	--	--	6,151	20	31	6,703
B-8-2 BOOSTER NOZZLE ATTACH CLAMP ASSEMBLY (INTEGRAL)	27.0	933	555	18,524	--	--	18,524	129	203	19,660
B-9 BOOSTER ATTACH CLAMP ASSEMBLY (NON-INTEGRAL)	27.0	933	555	18,524	--	--	18,524	129	203	19,660
B-11 CASE PORT COVER (ALUMINUM)	1.7	59	292	9,559	3,600	5,303	14,862	42	66	14,987
B-12 AFT SHROUD (NON-INTEGRAL BOOSTER)	66.1	2,283	734	24,625	--	--	24,625	23	36	26,944

TABLE 1-2. BASELINE COMPONENT COST ESTIMATES – UNIT NO. 1

STRUCTURAL MATERIAL 4130 STEEL

COMPONENT	(1) PRODUCTION MANHOURS	(2) PRODUCTION COST	(3) TOOLING MANHOURS	(4) TOOLING LABOR COST	(5) TOOLING MATERIALS NON RECURRING	(6) PURCHASED TOOLING COST	(7) TOTAL TOOLING COST (4) + (6)	(8) MATERIALS RECURRING	(9) PURCHASED MATERIALS RECURRING COST	(10) SELLING PRICE (2) + (7) + (9)
B-13 BOOSTER/COMBUSTOR OPTIONS										
B-13-1 FIXED LAUNCH RAIL (1 FITTING)	9.0	311	281	9,184	2,590	3,815	13,000	30	47	13,358
B-13-2 EXTERNAL FOLDING LAUNCH LUG	29.9	1,033	626	20,944	5,755	8,478	29,422	94	148	30,603
B-13-3 FOLDING LAUNCH LUG/SWAY BRACE/FAIRING SUPPORT	62.2	2,148	691	23,160	14,200	20,918	44,078	477	750	46,976
B-13-4 360° & 180° SWAY BRACE OR SUPPORT	33.1	1,143	538	17,945	--	--	17,945	24	38	19,126
B-13-7 STRONGBACK	18.0	622	145	4,549	--	--	4,549	12	19	5,190
C-4 FUEL TANK - LFRJ										
C-4-1 FUEL TANK WITH STANDPIPE AND FULL BLADDER										
C-4-1-1 ROLL AND WELD CONSTRUCTION	364.5	12,590	2,409	81,720	9,900	14,584	96,304	1,208	1,899	110,793
C-4-1-2 DEEP DRAW CONSTRUCTION	267.4	9,236	2,630	89,253	38,900	57,304	146,557	1,370	2,154	157,947
C-4-1-3 MACHINED FORGING WITH ROLL AND WELD CASE	341.5	11,795	2,894	98,251	9,900	14,584	112,835	1,528	2,402	127,032
C-4-1-4 MACHINED AND SHEAR SPUN CONSTRUCTION	340.9	11,775	3,064	104,046	9,900	14,584	118,630	1,802	2,833	133,238
C-4-2 FUEL TANK WITH HALF ROLLING DIAPHRAGM	447.3	15,450	2,246	76,164	4,000	5,892	82,056	714	1,123	98,629
C-5 PROPELLANT/OXIDIZER TANKS (LDR) (REF. C-4, LDR LIQUID FUEL AND OXIDIZER TANKS ARE SAME AS LFRJ LIQUID FUEL TANKS)										
C-8 FUEL MANIFOLDS AND INJECTORS										
C-8-1 WALL MOUNTED INJECTORS IN INLET PADS (PER INLET)	11.3	390	281	9,185	--	--	9,185	32	50	9,625
C-8-2 WALL MOUNTED INJECTORS AROUND INLET DUCT	127.7	4,411	429	14,229	--	--	14,229	57	90	18,730
C-8-3 INTERNAL STREAM INJECTORS (PER INLET)	18.8	649	476	15,831	3,500	5,156	20,987	165	259	21,895
C-8-4 INTERNAL STREAM INJECTOR FOR PODDED RAMJET	173.7	6,000	1,922	65,120	--	--	65,120	69	109	71,229
C-9 FUEL MANAGEMENT SYSTEM COMPARTMENT	169.4	5,851	284	9,287	--	--	9,287	35	55	15,193
C-10 GAS GENERATOR - LRDR	113.1	3,906	1,261	42,589	3,000	4,419	47,008	150	236	51,150
C-11 GAS GENERATOR NOZZLE	79.9	2,760	1,041	35,090	--	--	35,090	276	434	38,284
C-12 RAM AIR TURBINE SCOOP	18.4	636	384	12,695	4,500	6,629	19,324	513	806	20,766
C-13 FUEL SYSTEM OPTIONS										
C-13-1 FUEL TANK FIXED LAUNCH RAIL (1 FITTING)	9.0	311	281	9,184	2,590	3,815	13,000	15	24	13,335
C-13-2 FUEL TANK EXTERNAL FOLDING LAUNCH LUG	29.9	1,033	626	20,944	5,755	8,478	29,422	94	148	30,603
C-13-3 SUBMERGED FOLDING LAUNCH LUG AND TANK SWAY BRACE	100.8	3,482	854	28,716	16,500	24,306	53,022	506	796	57,300
C-13-4 FMS COMPARTMENT SUBMERGED FOLDING LAUNCH LUG	37.0	1,278	626	20,944	6,222	9,166	30,110	94	148	31,536
C-13-5 FUEL TANK FOLDING LAUNCH LUG/SWAY BRACE/FAIRING SUPPORT	62.2	2,148	691	23,160	14,200	20,918	44,078	477	750	46,976
C-13-6 360° & 130° SWAY BRACE OR SUPPORT	33.1	1,143	538	17,945	--	--	17,945	24	38	19,126
C-13-7 FUEL TANK STRONGBACK	18.0	622	145	4,549	--	--	4,549	12	19	5,190

TABLE 1-2. BASELINE COMPONENT COST ESTIMATES – UNIT NO. 1

STRUCTURAL MATERIAL 4130 STEEL

COMPONENT	(1) PRODUCTION MANHOURS	(2) PRODUCTION COST	(3) TOOLING MANHOURS	(4) TOOLING LABOR COST	(5) TOOLING MATERIALS NON-RECURRING	(6) PURCHASED TOOLING COST	(7) TOTAL TOOLING COST (4) + (6)	(8) MATERIALS RECURRING	(9) PURCHASED MATERIALS RECURRING COST	(10) SELLING PRICE (2) + (7) + (9)
C-13-8 PODDED ENGINE MOUNT LUG	18.5	639	464	15,422	--	--	15,422	38	60	16,121
C-13-9 EXTERNAL INSULATION	17.7	611	6	195	--	--	195	59	93	899
C-13-10 WIRING & PLUMBING TUNNEL	23.8	822	1,312	44,327	--	--	44,327	18	20	45,169
D-3 GAS GENERATOR CHAMBER ASSEMBLY (SFDR)										
D-3-1 ROLL AND WELD CONSTRUCTION	293.3	10,131	3,584	121,771	--	--	121,771	145	228	132,130
D-3-2 DEEP DRAW CONSTRUCTION	232.4	8,027	3,198	108,613	52,000	76,602	185,215	248	390	193,632
D-3-3 MACHINED AND SHEAR SPUN CONSTRUCTION	320.8	11,080	3,247	110,284	12,000	17,677	127,961	658	1,034	140,075
D-4 SOLID DUCTED ROCKET NOZZLE ASSEMBLY	79.9	2,760	1,041	35,090	--	--	35,090	276	434	38,284
D-5 SOLID FUEL SYSTEM OPTIONS										
D-5-1 FIXED LAUNCH RAIL (1 FITTING)	9.0	311	281	9,184	2,590	3,815	13,000	30	47	13,358
D-5-2 EXTERNAL FOLDING LAUNCH LUG	29.9	1,033	626	20,944	5,755	8,478	29,422	94	148	30,603
D-5-3 FOLDING LAUNCH LUG/SWAY BRACE/FAIRING SUPPORT	62.2	2,148	691	23,160	14,200	20,918	44,078	477	750	46,976
D-5-4 360° & 180° SWAY BRACE OR SUPPORT	33.1	1,143	538	17,945	--	--	17,945	24	38	19,126
D-5-5 STRONGBACK	18.0	622	145	4,549	--	--	4,549	12	19	5,190
FINAL ASSEMBLY (DOES NOT INCLUDE SYSTEMS CHECKOUT)										
E-1 LIQUID FUEL RAMJET - INTEGRAL ROCKET - RAMJET	159.0	5,492	3,240	110,045	--	--	110,045	1,521	2,391	117,928
E-2 LIQUID FUEL RAMJET - STAGED BOOSTER	182.4	6,300	3,240	110,045	--	--	110,045	2,042	3,210	109,555
E-3 LIQUID FUEL RAMJET - PODDED	152.8	5,278	3,743	127,190	--	--	127,190	2,604	4.094	136,562
E-4 SOLID FUEL RAMJET - INTEGRAL ROCKET - RAMJET	104.5	3,609	2,818	95,661	--	--	95,661	1,304	2,050	101,320
E-5 SOLID FUEL DUCTED ROCKET - INTEGRAL ROCKET - RAMJET	126.0	4,352	3,204	108,818	--	--	108,818	1,304	2,050	115,220
E-6 SOLID FUEL DUCTED ROCKET - STAGED BOOSTER	151.5	5,233	3,204	108,818	--	--	108,818	1,824	2,868	116,919
E-7 LIQUID FUEL DUCTED ROCKET - INTEGRAL ROCKET - RAMJET	190.2	6,570	3,204	108,818	--	--	108,818	1,611	2,533	117,921
E-8 LIQUID FUEL DUCTED ROCKET - STAGED BOOSTER	226.7	7,830	3,240	110,045	--	--	110,045	2,132	3,352	121,227

TABLE 1-3. BASELINE COMPONENT COST ESTIMATES – UNIT NO. 1

STRUCTURAL MATERIAL INCONEL 718

COMPONENT	(1) PRODUCTION MANHOURS	(2) PRODUCTION COST	(3) TOOLING MANHOURS	(4) TOOLING LABOR COST	(5) TOOLING MATERIALS NON-RECURRING	(6) PURCHASED TOOLING COST	(7) TOTAL TOOLING COST (4) + (6)	(8) MATERIALS RECURRING	(9) PURCHASED MATERIALS RECURRING COST	(10) SELLING PRICE (2) + (7) + (9)
A-1 INLET ASSEMBLIES										
A-1-1 2-D AFT INLET ASSEMBLY - CAST	490.6	16,945	751	25,205	85,000	125,215	150,420	4,513	7,095	174,460
A-1-2 2-D AFT INLET ASSEMBLY - SHEET METAL	510.2	17,622	2,408	81,686	--	--	81,685	347	545	99,852
A-1-3 AXISYMMETRIC AFT INLET ASSEMBLY - CAST	89.9	3,105	2,345	79,538	52,524	77,374	156,912	1,279	2,011	162,028
A-1-4 AXISYMMETRIC AFT INLET ASSEMBLY - SHEET METAL	318.2	10,991	2,984	101,319	--	--	101,319	749	1,178	113,488
A-1-5 CHIN INLET ASSEMBLY - CAST/SHEET METAL	458.7	15,843	5,116	173,990	122,000	179,721	353,711	10,386	16,328	385,882
A-1-6 CHIN INLET ASSEMBLY - SHEET METAL	1352.2	46,705	10,495	357,339	--	--	357,339	1,777	2,794	406,838
A-1-7 AXISYMMETRIC PODDED INLET ASSEMBLY - CAST/SHEET METAL	399.1	13,785	1,124	37,919	14,000	20,624	58,543	2,157	3,391	75,719
A-1-8 PITOT PODDED INLET ASSEMBLY - SHEET METAL	243.7	8,417	374	12,355	--	--	12,355	199	314	21,086
A-2 INLET AFT FAIRINGS										
A-2-1 2-D AFT INLET AFT FAIRING	102.9	3,554	699	23,432	--	--	23,432	176	277	27,263
A-2-2 AXISYMMETRIC AFT INLET AFT FAIRING	104.1	3,596	699	23,432	--	--	23,432	213	336	27,364
A-2-3 CHIN INLET AFT FAIRING	99.5	3,437	2,817	94,627	3,000	4,419	100,046	1,259	1,979	105,462
A-3 INLET SIDE FAIRINGS										
A-3-1 2-D AFT INLET SIDE FAIRING	74.5	2,573	447	14,843	--	--	14,843	202	318	17,734
A-3-2 AXISYMMETRIC AFT INLET SIDE FAIRING	76.3	2,635	447	14,843	--	--	14,843	196	309	17,787
A-4 POD ATTACH FAIRING	150.9	5,212	850	28,580	--	--	28,580	615	968	34,760
A-5 OPTIONS										
A-5-1 2-D INLET COVER	54.6	1,886	586	19,581	--	--	19,581	889	1,398	22,865
A-5-2 AXISYMMETRIC INLET COVER	51.9	1,793	989	33,317	--	--	33,317	862	1,356	36,466
A-5-3 CHIN INLET COVER	67.8	2,342	1,119	37,749	3,000	4,419	42,168	793	1,247	45,757
A-5-4 AIRFOIL TYPE AERODYNAMIC GRID - 2-D	14.9	515	280	9,150	3,000	4,419	13,569	82	129	14,213
A-5-5 AIRFOIL TYPE AERODYNAMIC GRID - CIRCULAR	25.6	884	145	4,549	4,000	5,892	10,441	125	196	11,521
B-1 COMBUSTOR CHAMBER ASSEMBLY (INTEGRAL OR NON-INTEGRAL DESIGN)										
B-1-1 CHAMBER FOR AFT INLET DESIGN (LFRJ)										
B-1-1-1 ROLL AND WELD CONSTRUCTION	1065.1	36,789	5,396	183,534	6,200	9,133	192,667	1,185	1,863	231,319
B-1-1-2 DEEP DRAW CONSTRUCTION	740.2	25,567	4,280	145,494	86,200	126,983	272,477	1,687	2,652	300,696
B-1-1-3 MACHINED & SHEAR SPUN CONSTRUCTION	2129.6	73,556	7,645	260,194	18,200	26,811	287,005	5,441	8,554	369,115
B-1-2 CHAMBER FOR CHIN INLET DESIGN (LFRJ)										
B-1-2-1 ROLL AND WELD CONSTRUCTION	512.9	17,716	1,932	65,460	--	--	65,460	486	764	83,940
B-1-2-2 DEEP DRAW CONSTRUCTION	277.7	9,592	1,546	52,303	52,000	76,602	128,905	1,159	1,822	140,319
B-1-2-3 MACHINED & SHEAR SPUN CONSTRUCTION	1472.8	50,871	6,540	222,529	12,000	17,677	240,206	3,524	5,540	296.617

TABLE 1-3. BASELINE COMPONENT COST ESTIMATES – UNIT NO. 1

STRUCTURAL MATERIAL INCONEL 718

COMPONENT	(1) PRODUCTION MANHOURS	(2) PRODUCTION COST	(3) TOOLING MANHOURS	(4) TOOLING LABOR COST	(5) TOOLING MATERIALS NON RECURRING	(6) PURCHASED TOOLING COST	(7) TOTAL TOOLING COST (4) + (6)	(8) MATERIALS RECURRING	(9) PURCHASED MATERIALS RECURRING COST	(10) SELLING PRICE (2) + (7) + (9)
B-1-3 CHAMBER FOR PODDED DESIGN (LFRJ) ROLL & WELD	324.0	11,191	899	30,250	--	--	30,250	424	667	42,108
B-1-4 CHAMBER FOR AFT INLET DESIGN (SFRJ)										
B-1-4-1 ROLL AND WELD CONSTRUCTION	1002.0	34,609	5,269	179,206	26,200	38,596	217,802	1,367	2,149	254,560
B-1-4-2 DEEP DRAW CONSTRUCTION	870.9	30,081	4,981	169,398	26,200	38,596	207,965	1,610	2,531	240,577
B-1-4-3 MACHINED AND SHEAR SPUN CONSTRUCTION	2377.4	82,115	9,136	311,016	22,200	32,703	343,719	4,878	7,669	433,503
B-1-5 CHAMBER FOR AFT INLET DESIGN (SFDR OR LFDR)										
B-1-5-1 ROLL AND WELD CONSTRUCTION	1093.4	37,766	5,591	190,181	6,200	9,133	199,314	1,289	2,026	239,106
B-1-5-2 DEEP DRAW CONSTRUCTION	792.1	27,359	4,540	154,357	86,200	126,983	281,340	1,781	2,800	311,499
B-1-5-3 MACHINED AND SHEAR SPUN CONSTRUCTION	2094.8	72,354	7,645	260,194	18,200	26,811	287,005	5,441	8,554	367,913
B-2 BOOSTER CHAMBER ASSEMBLY (FOR NON-INTEGRAL BOOSTER ONLY)										
B-2-1 STAGED (SEPARABLE)										
B-2-1-1 ROLL AND WELD CONSTRUCTION	966.1	33,369	2,569	87,173	--	--	87,173	1,313	2,064	122,606
B-2-1-2 DEEP DRAW CONSTRUCTION	751.5	25,957	2,167	73,471	29,000	42,720	116,191	2,061	3,240	145,388
B-2-2 NON-STAGED										
B-2-2-1 ROLL AND WELD CONSTRUCTION	542.8	18,748	2,523	85,605	--	--	85,605	628	987	105,340
B-2-2-2 DEEP DRAW CONSTRUCTION	549.5	18,980	2,121	71,903	29,000	42,700	114,623	1,376	2,163	135,766
B-3 SUSTAINER NOZZLE ASSEMBLY										
B-3-1 SILICA PHENOLIC INSERT	444.4	15,350	1,797	60,859	5,375	7,918	68,777	1,086	1,708	85,835
B-3-2 METALLIC/SILICA PHENOLIC	629.1	21,729	2,281	77,356	2,400	3,535	80,891	1,025	1,611	104,231
B-7 BOOSTER NOZZLE ASSEMBLY										
B-7-1 NOZZLE FOR INTEGRAL DESIGN										
B-7-1-1 SILICA PHENOLIC WITH GRAPHITE THROAT	67.1	2,318	613	20,501	--	--	20,501	337	530	23,349
B-7-1-2 SILICA PHENOLIC WITH METALLIC STRUCTURE #1	77.5	2,677	613	20,501	--	--	20,501	456	717	23,895
B-7-2 NOZZLE FOR NON-INTEGRAL BOOSTER										
B-7-2-1 SILICA PHENOLIC/METAL/GRAPHITE	453.0	15,647	1,411	47,702	--	--	47,701	476	748	64,096
B-8 BOOSTER NOZZLE RETENTION ASSEMBLY (INTEGRAL)										
B-8-1 BOOSTER NOZZLE RETENTION ASSEMBLY (INTEGRAL)	66.8	2,307	192	6,151	--	--	6,151	66	104	8,562
B-8-2 BOOSTER NOZZLE ATTACH CLAMP ASSEMBLY (INTEGRAL)	109.3	3,775	555	18,524	--	--	18,524	269	423	22,722
B-9 BOOSTER ATTACH CLAMP ASSEMBLY (NON-INTEGRAL)	109.3	3,775	555	18,524	--	--	18,524	269	423	22,722
B-11 CASE PORT COVER (ALUMINUM)	1.7	59	292	9,559	3,600	5,303	14,862	42	66	14,987
B-12 AFT SHROUD (NON-INTEGRAL BOOSTER)	237.7	8,210	525	17,501	--	--	17,501	176	277	25,988

TABLE 1-3. BASELINE COMPONENT COST ESTIMATES – UNIT NO. 1

STRUCTURAL MATERIAL INCONEL 718

COMPONENT	(1) PRODUCTION MANHOURS	(2) PRODUCTION COST	(3) TOOLING MANHOURS	(4) TOOLING LABOR COST	(5) TOOLING MATERIALS NON-RECURRING	(6) PURCHASED TOOLING COST	(7) TOTAL TOOLING COST (4) + (6)	(8) MATERIALS RECURRING	(9) PURCHASED MATERIALS RECURRING COST	(10) SELLING PRICE (2) + (7) + (9)
B-13 BOOSTER/COMBUSTOR OPTIONS										
B-13-1 FIXED LAUNCH RAIL (1 FITTING)	36.1	1,247	281	9,184	2,652	3,907	13,091	122	191	14,529
B-13-2 EXTERNAL FOLDING LAUNCH LUG	92.9	3,209	626	20,944	6,222	9,166	30,110	326	512	33,831
B-13-3 FOLDING LAUNCH LUG/SWAY BRACE/FAIRING SUPPORT	169.4	5,851	691	23,160	14,200	20,918	44,078	842	1,324	51,253
B-13-4 360° & 180° SWAY BRACE OR SUPPORT	56.9	1,965	329	10,821	--	--	10,821	130	204	12,990
B-13-7 STRONGBACK	17.3	598	145	4,549	--	--	4,549	88	138	5,285
C-4 FUEL TANK - LFRJ										
C-4-1 FUEL TANK WITH STANDPIPE AND FULL BLADDER										
C-4-1-1 ROLL AND WELD CONSTRUCTION	1133.3	39,144	2,150	72,891	9,900	14,584	87,475	1,665	2,618	129,237
C-4-1-2 DEEP DRAW CONSTRUCTION	767.0	26,492	2,397	81,310	38,900	57,304	138,614	2,433	3,825	168,931
C-4-1-3 MACHINED FORGING WITH ROLL AND WELD CASE	1339.0	46,249	2,239	75,925	9,900	14,584	90,509	3,535	5,558	142,316
C-4-1-4 MACHINED AND SHEAR SPUN CONSTRUCTION	1287.5	44,470	2,831	96,104	9,900	14,584	110,688	4,837	7,605	162,763
C-4-2 FUEL TANK WITH HALF ROLLING DIAPHRAGM	1259.7	43,510	2,246	76,164	4,000	5,892	82,056	2,237	3,517	129,083
C-5 PROPELLANT/OXIDIZER TANKS (LDR) (REF. C-4, LDR LIQUID FUEL AND OXIDIZER TANKS ARE SAME AS LFRJ LIQUID FUEL TANKS)										
C-8 FUEL MANIFOLDS AND INJECTORS										
C-8-1 WALL MOUNTED INJECTORS IN INLET PADS (PER INLET)	28.0	967	281	9,185	--	--	9,185	32	50	10,202
C-8-2 WALL MOUNTED INJECTORS AROUND INLET DUCT	278.6	9,623	429	14,229	--	--	14,229	102	160	24,012
C-8-3 INTERNAL STREAM INJECTORS (PER INLET)	66.9	2,311	476	15,831	3,500	5,156	20,987	210	330	23,628
C-8-4 INTERNAL STREAM INJECTOR FOR PODDED RAMJET	402.1	13,889	1,922	65,120	--	--	65,120	350	550	79,559
C-9 FUEL MANAGEMENT SYSTEM COMPARTMENT	456.8	15,778	284	9,287	--	--	9,287	256	402	25,467
C-10 GAS GENERATOR - LRDR	351.8	12,151	1,052	35,465	3,000	4,419	39,884	577	907	52,942
C-11 GAS GENERATOR NOZZLE	281.4	9,719	832	27,966	--	--	27,966	768	1,207	38,892
C-12 RAM AIR TURBINE SCOOP	64.2	2,217	384	12,695	4,500	6,629	19,324	685	1,077	22,618
C-13 FUEL SYSTEM OPTIONS										
C-13-1 FUEL TANK FIXED LAUNCH RAIL (1 FITTING)	36.1	1,247	281	9,184	2,652	3,907	13,091	122	191	14,529
C-13-2 FUEL TANK EXTERNAL FOLDING LAUNCH LUG	92.9	3,209	626	20,944	6,222	9,166	30,110	326	512	33,831
C-13-3 SUBMERGED FOLDING LAUNCH LUG AND TANK SWAY BRACE	212.0	7,322	854	28,715	16,500	24,306	53,021	1,311	2,061	62,404
C-13-4 FMS COMPARTMENT SUBMERGED FOLDING LAUNCH LUG	85.0	2,934	626	20,944	6,222	9,166	30,110	326	512	33,556
C-13-5 FUEL TANK FOLDING LAUNCH LUG/SWAY BRACE/FAIRING SUPPORT	169.4	5,851	691	23,160	14,200	20,918	44,078	842	1,324	51,253
C-13-6 360° & 180° SWAY BRACE OR SUPPORT	56.9	1,965	329	10,821	--	--	10,821	130	204	12,990
C-13-7 FUEL TANK STRONGBACK	17.3	598	145	4,549	--	--	4,549	88	138	5,285

TABLE 1-3. BASELINE COMPONENT COST ESTIMATES – UNIT NO. 1

STRUCTURAL MATERIAL INCONEL 718

COMPONENT	(1) PRODUCTION MANHOURS	(2) PRODUCTION COST	(3) TOOLING MANHOURS	(4) TOOLING LABOR COST	(5) TOOLING MATERIALS NON RECURRING	(6) PURCHASED TOOLING COST	(7) TOTAL TOOLING COST (4) + (6)	(8) MATERIALS RECURRING	(9) PURCHASED MATERIALS RECURRING COST	(10) SELLING PRICE (2) + (7) + (9)
C-13-8 PODDED ENGINE MOUNT LUG	57.6	1,990	464	15,422	--	--	15,422	283	445	17,857
C-13-9 EXTERNAL INSULATION	17.7	611	6	195	--	--	195	59	93	899
C-13-10 WIRING & PLUMBING TUNNEL	38.8	1,340	1,312	44,327	--	--	44,327	168	264	45,931
D-3 GAS GENERATOR CHAMBER ASSEMBLY (SFDR)										
D-3-1 ROLL AND WELD CONSTRUCTION	888.5	30,689	2,833	96,172	--	--	96,172	881	1,385	128,246
D-3-2 DEEP DRAW CONSTRUCTION	660.4	22,810	2,447	83,015	52,000	76,602	159,617	1,574	2,475	184,902
D-3-3 MACHINED AND SHEAR SPUN CONSTRUCTION	1287.2	44,460	2,496	84,685	12,000	17,677	102,362	3,850	6,053	152,875
D-4 SOLID DUCTED ROCKET NOZZLE ASSEMBLY	281.4	9,719	832	27,966	--	--	27,966	768	1,207	38,892
D-5 SOLID FUEL SYSTEM OPTIONS										
D-5-1 FIXED LAUNCH RAIL (1 FITTING)	36.1	1,247	281	9,184	2,652	3,907	13,091	122	191	14,529
D-5-2 EXTERNAL FOLDING LAUNCH LUG	92.9	3,209	626	20,944	6,222	9,166	30,110	326	512	33,831
D-5-3 FOLDING LAUNCH LUG/SWAY BRACE/FAIRING SUPPORT	169.4	5,851	691	23,160	14,200	20,918	44,078	842	1,324	51,253
D-5-4 360° & 180° SWAY BRACE OR SUPPORT	56.9	1,965	329	10,821	--	--	10,821	130	204	12,990
D-5-5 STRONGBACK	17.3	598	145	4,549	--	--	4,549	88	138	5,285
FINAL ASSEMBLY (DOES NOT INCLUDE SYSTEMS CHECKOUT)										
E-1 LIQUID FUEL RAMJET - INTEGRAL ROCKET - RAMJET	188.9	6,525	3,240	110,045	--	--	110,045	1,521	2,391	118,961
E-2 LIQUID FUEL RAMJET - STAGED BOOSTER	221.7	7,658	3,240	110,045	--	--	110,045	2,042	3,210	120,913
E-3 LIQUID FUEL RAMJET - PODDED	180.2	6,224	3,743	127,190	--	--	127,190	2,604	4,094	137,508
E-4 SOLID FUEL RAMJET - INTEGRAL ROCKET - RAMJET	124.8	4,311	2,818	95,661	--	--	95,661	1,304	2,050	102,022
E-5 SOLID FUEL DUCTED ROCKET - INTEGRAL ROCKET - RAMJET	151.4	5,229	3,204	108,818	--	--	108,818	1,304	2,050	116,097
E-6 SOLID FUEL DUCTED ROCKET - STAGED BOOSTER	188.8	6,521	3,204	108,818	--	--	108,818	1,824	2,868	118,207
E-7 LIQUID FUEL DUCTED ROCKET - INTEGRAL ROCKET - RAMJET	226.1	7,809	3,204	108,818	--	--	108,818	1,611	2,533	119,160
E-8 LIQUID FUEL DUCTED ROCKET - STAGED BOOSTER	266.5	9,205	3,240	110,045	--	--	110,045	2,132	3,352	122,602

TABLE 1-4. BASELINE COMPONENT COST ESTIMATES – UNIT NO. 1 (SUBCONTRACTED SERVICES/MATERIALS)

COMPONENT	(1) PRODUCTION COST	(2) TOTAL TOOLING COST	(3) PURCHASED MATERIALS RECURRING COST
B-6 BOOSTER PROPELLANT			
B-6-1 PROPELLANT FOR INTEGRAL BOOSTER (SFRJ)			
B-6-1-1 HTPB HIGH SMOKE	7,019	306,235	771
B-6-1-1 HTPB LOW SMOKE	7,019	306,235	649
B-6-1-2 CTPB HIGH SMOKE	7,019	306,235	1,043
B-6-1-2 CTPB LOW SMOKE	7,019	306,235	810
B-6-2 PROPELLANT FOR INTEGRAL BOOSTER (LFRJ, DR)			
B-6-2-1 HTPB HIGH SMOKE	4,834	163,326	2,477
B-6-2-1 HTPB LOW SMOKE	4,834	163,326	2,364
B-6-2-2 CTPB HIGH SMOKE	4,803	177,838	2,755
B-6-2-2 CTPB LOW SMOKE	4,803	177,838	2,644
B-6-3 PROPELLANT FOR NON-INTEGRAL BOOSTER			
B-6-3-1 HTPB HIGH SMOKE	13,680	40,998	1,092
B-6-3-1 HTPB LOW SMOKE	13,680	40,998	976
B-6-3-2 CTPB HIGH SMOKE	13,680	40,998	1,390
B-6-3-2 CTPB LOW SMOKE	13,680	40,998	1,274
B-7 BOOSTER NOZZLE ASSEMBLY			
B-7-1 NOZZLE FOR INTEGRAL DESIGN			
B-7-1-3 SILICA PHENOLIC WITH METALLIC STRUCTURE #2	496	27,318	4,815
B-7-1-4 CONSUMABLE BOOSTER NOZZLE			
B-7-1-4-1 HTPB HIGH SMOKE	1,269	4,008	271
B-7-1-4-2 HTPB LOW SMOKE	1,269	4,008	241
B-7-1-4-3 CTPB HIGH SMOKE	1,233	4,008	352
B-7-1-4-4 CTPB LOW SMOKE	1,233	4,008	320
B-7-2 NOZZLE FOR NON-INTEGRAL BOOSTER			
B-7-2-2 CONSUMABLE BOOSTER NOZZLE			
B-7-2-2-1 HTPB HIGH SMOKE	339	4,539	122
B-7-2-2-2 HTPB LOW SMOKE	339	4,539	109
B-7-2-2-3 CTPB HIGH SMOKE	355	4,539	160
B-7-2-2-4 CTPB LOW SMOKE	355	4,539	146
B-13 BOOSTER/COMBUSTOR OPTIONS			
B-13-5 THERMAL INSULATION (LFRJ OR DR)			
B-13-5-1 PTV VENTED	9,384	289,078	982
B-13-5-2 SRL VENTED	7,328	289,078	982
B-13-5-3 CONTINUOUS	3,712	42,453	982
B-13-6 THERMAL INSULATION (SFRJ)			
B-13-6-1 VENTED	13,842	385,437	2,089
B-13-6-2 CONTINUOUS	5,476	56,604	2,089
D-1 FUEL - SFDR			
D-1-1 60% MAGNESIUM (CAST)	13,912	163,326	3,726
D-1-2 60% MAGNESIUM (PRESSED)	16,042	163,326	3,309
D-2 FUEL - SFRJ			
D-2-1 UT-18818 (LOW SMOKE)	3,934	306,235	531
D-2-2 UT-14649 (HIGH SMOKE)	3,934	306,235	665

TABLE 1-5. BASELINE COMPONENT COST ESTIMATES – UNIT NO. 1

(PURCHASED COMPONENTS)

COMPONENT	SELLING PRICE (1)
B-4 SUSTAINER IGNITER ASSEMBLY	
B-4-1 LIQUID FUEL RAMJET IGNITER	
B-4-1-1 EXTERNALLY LOCATED - DUAL INITIATORS	9,127
B-4-1-1 EXTERNALLY LOCATED - DUAL BRIDGEWIRES	8,116
B-4-1-1 EXTERNALLY LOCATED - SIMPLE NOZZLE	7,483
B-4-1-2 INTERNALLY LOCATED - NON-HERMETIC SINGLE IGNITION	555
B-4-1-2 INTERNALLY LOCATED - NON-HERMETIC DUAL IGNITION	655
B-4-1-2 INTERNALLY LOCATED - HERMETIC SINGLE IGNITION	966
B-4-1-2 INTERNALLY LOCATED - HERMETIC DUAL IGNITION	1,077
B-4-2 SOLID DUCTED ROCKET IGNITER	2,936
B-5 BOOSTER IGNITER ASSEMBLY	
B-5-1 HEAD END IGNITER	1,970
B-5-2 NOZZLE MOUNTED IGNITER	2,936
B-10 DOME PORT COVER	1,545
B-13 BOOSTER/COMBUSTOR OPTIONS	
B-13-8 IGNITER SAFE/ARM ASSEMBLY	
B-13-8-1 EBW WITH FIRING UNIT	761
B-13-8-2 TBI WITH TRANSFER	1,195
B-13-8-3 S/A MANUAL ACTUATION	1,520
B-13-8-4 S/A MANUAL ACTUATION, TEST POSITION	1,739
B-13-8-5 S/A ELECTRICAL ENABLE, MANUAL/LANYARD ACTUATION, TEST POSITION, ARM DELAY	4,345
C-1 SUSTAINER FUEL -LFRJ	
C-1-1 JP-5	11
C-1-2 SHELLDYNE	1,021
C-1-3 TH DIMER	30
C-1-4 SI-80	973
C-2 SUSTAINER FUEL - LFDR	
C-2-1 UDMH	803
C-2-2 HYDRAZINE	355
C-2-3 MMH	503
C-3 SUSTAINER OXIDIZER - LFDR	
C-3-1 IRFNA	40
C-3-2 NITROGEN TETROXIDE	29
C-6 FUEL MANAGEMENT SYSTEM (LFRJ)	
C-6-1 FUEL DELIVERY SYSTEM	
C-6-1-1 TURBOPUMP	138,731
C-6-1-2 SOLID PROPELLANT GAS GENERATOR - SINGLE CONTAINER	39,476
C-6-1-2 SOLID PROPELLANT GAS GENERATOR - TWO CONTAINERS	47,232
C-6-2 FUEL CONTROL SYSTEM	
C-6-2-1 SINGLE FLOWRATE	571
C-6-2-1 2-FLOWRATES - STEPPED	1,508
C-6-2-1 3-FLOWRATES - STEPPED	2,187
C-6-2-1 7-FLOWRATES - STEPPED	3,779
C-6-2-2 PNEUMATIC ALTITUDE SCHEDULED FUEL CONTROL - HYDRAULIC AMPLIFICATION	101,108
C-6-2-2 PNEUMATIC ALTITUDE SCHEDULED FUEL CONTROL - MECHANICAL AND HYDRAULIC AMPLIFICATION	263,453
C-6-2-3 ELECTRONIC FUEL/AIR RATIO CONTROL WITH PR AND MN LIMITERS	284,019
C-6-2-3 PNEUMATIC FUEL/AIR RATIO CONTROL WITH PR AND MN LIMITERS	206,393
C-7 FUEL MANAGEMENT SYSTEM (LDR) (COST FACTORS DEVELOPED TO CONVERT LFRJ FMS COSTS TO LDR FMS COSTS)	

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